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Thème

Rationalisation de la consummation de l'énergie électrique et thermique dans le batiment cas de Sétif

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ABSTRACT

The need for a strategy to reduce energy consumption and CO2 emissions, especially in residential buildings is highly recommended, According to the energy outlook 2035 insights, the consumption of different fuel types, from1965 to 2035 is expected to increase by 27.5% for oil, 26.4 % for gas, 26.8% for coal, 4.9% for nuclear, 7.2 for hydro, and 7.2 for renewable energies. Buildings represent the most energy consuming sector in the economy, well before industry and transport sectors, and account for over one third of total final energy consumption and as a result one third global carbon emissions, and half of global electricity is consumed in buildings. Global energy demand in the residential sector grew by14% between 2000 and 2011.

Since the energy crises of 1973, most of the world countries started thinking about strategies and policies to reduce energy consumption in all sectors and activities, the first driving raison was purely economic, environmental reasons were added later on. During this crisis, legislative texts regulating the use of energy were promulgated, and the automatisation of systems consuming energy was adressed in all kind of activities.

The main target of the Doctoral thesis is an “Optimal retrofit model to reduce the energy consumption in multi-apartment dwelling buildings”. In this thesis, the importance of energy consumption and its environmental and economical impact is developed in the introduction, in the first chapter, the world energy consumption in general and particulary in the residential sector is analysed.

An analytical study of the most used whole building simulation software programs, eQUEST and EnergyPlus, is done, and a conclusion that eQUEST is more convenient as an early stage tool to evaluate energy consumption is drawn. In the third chapter, an analysis of residential energyconsumtion in Algeria is performed. A study of space heating energy consumption in typical residential buildings developed in chapter 4. In chapter 5, theoretical models of residential building energy consumption are reviewed. Astudy of different scenarios of renovation of exterior building envelope insulation, with different insulation material, and different thicknesses, as well as the effect of glass type and categories, on heating space energy consumption, and as fixed by the target of the thesis, a new combined model (scenario) enabling 25% of energy savings is elaborated and is presented inthesixth chapter followed by the seventh chapter for general conclusions.

CONTENTS

SYMBOLS AND ABBREVIATIONS

Symbols	Units	Description
A_{ij}	m^2	Area of the j^{th} element
$A_{i,j}$	m^2	Area of the i^{th} and $i+1^{th}$layer of j^{th} element
$C_{p,b}$	$\frac{J}{kg.K}$	Spcific heat capacity of moist air inside the building unit
$C_{pi,j}$	$\frac{J}{kg.K}$	Specifique heat capacity of the ith layer of the jth element
$\dot{E}_x$	W	Total energy flow rate to the x direction
$\dot{H}_x$	W	Enthalpy flow rate to the x direction
h_x	$\frac{J}{kg}$	Specific enthalpy of incoming air to the x direction
$h_{b,j}$	$\frac{W}{m^2.K}$	Convection heat transfer coefficient of j^{th} element inside the building unit
$h_{\infty,j}$	$\frac{W}{m^2.K}$	Convection heat transfer coefficient of j^{th} element outside the building unit
$K_{i,j}$	$\frac{W}{m.K}$	Thermal conductivity of i^{th} layer of j^{th} element
$l_{i,j}$	m	Half thickness of i^{th} layer of j^{th} element
M_b	$\frac{kg}{mol}$	Average molar mass of moist air in building unit
m_b	kg	Mass of air water mixture in unit building
$\left(P\dot{V}\right)^x$	W	Pressure work to the *x* direction
$\dot{Q}_j$	W	Heat gain or loss due to the j^{th} element
$\dot{q}_{i,j}$	W	Heat generation in i^{th} layer of j^{th} element
R	$\frac{Pa.m^3}{mol.K}$	Gas constant
r	m	Radius of a sphere
$\delta_{ri,fur}$	m	Half thikness of i^{th} layer in spherical furniture
T_∞	K	Outside Temperature
T_b	K	Temperature of the air in building unit
T_{centre}	K	Temperature of the centre of the assumed fourniture sphere
$T_{i,j}$	K	Temperature of the i^{th} layer of j^{th} element
$T^s_{i,j}$	K	Temperature of the $(i\text{-}1)^{th}$ and i^{th} layer of the j^{th} element
t	s	Time
U_j	$\frac{W}{m^2.K}$	Overall heat transfer coefficient of j^{th}element

ρ_{in}	$\frac{kg}{m^3}$	Density of the moist air flowing in the unit building
$\rho_{i,j}$	$\frac{kg}{m^3}$	Density of i^{th} layer of the j^{th} element
$\alpha_{i,j}$	$\frac{m^2}{s}$	Thermal diffusivity of the i^{th} layer of the j^{th} element
ε	-	Emissivity of the surface
σ	$\frac{W}{m^2.K}$	Stefan-Boltzmann constant
AFREC	-	African energycommission
AIEA	-	Agence internationale de l'énergie atomique
B2B	-	Business to business
BLAST	-	Basic local alignment search tool
Bsim	-	Building simulation program
CHP	-	Combined heat and power
DeST	-	Designers simulation toolkit
DHW	-	Domestic hot water
DOE	-	Department of Energy USA
ECOTECT	-	Autodesk environmental analysis tool
Ener.Win	-	Energy simulation software for buildings
ESPr	-	Modelling tool for building performance simulation
GDP	-	Gross domestic product
GHG	-	Greenhouse gas
HAP	-	Hourly analysis program
HVAC	-	Heating, ventilation , and air-conditionning
ICE	-	Indoor energy simulation program
IDA	-	Indoor climate and energy simulation program
IEF	-	International energy forum
IES VE	-	Energy Simulation program
IRENA	-	International agency for renewable energy
JODI	-	Joint oil data initiative
LPG	-	Liquified propane gas
LVS	-	Latvian standards
MENA	-	Middle East and North Africa
NEPAD	-	New partnership for Africa development
OECD	-	Organisation for economic co-operation development
PNEE	-	Programme national pour l'efficacitéénergétique
PNER	-	Programme national pour les énergies renouvelables
SCP	-	Sustainable consumption and production
SUNREL	-	Energy Simulation program
TFC	-	Total final consumption
TRACE	-	Trane air conditionning economics
TRNSYS	-	Energy Simulation program
TSGP	-	Trans-saharian gas pipeline

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INTRODUCTION

The need for the reduction of energy consumption and CO_2 emissions, in our daily life is more than a must, According to the energy outlook 2035 insights, the consumption of different fuel types, from1965 to 2035 is expected to increase by 27.5% for oil, 26.4 % for gas, 26.8% for coal, 4.9% for nuclear, 7.2 for hydro, and 7.2 for renewable energies. The global warming and the raise of temperature in the world climate are much more than it was expected to be. The more the atmosphere heats, the more the natural disasters occurs, ice melting, flood, tsunamis, and so on, examples of these disasters all over the world are more than obvious. This global heating of the climate is due to the increase of CO_2 emissions in the atmosphere. The reason for this CO_2 emissions increase is directly related to the excess of the use of fossil fuel in different sectors of activities. Share of global emissions in year 2012 are, coal 43%, oil 33%, gas 18%, and cement 5%. Buildings represent the most energy consuming sector in the economy, well before industry and transport sectors, and account for over one third of total final energy consumption and as a result one third global carbon emissions, and half of global electricity is consumed in buildings [**1**], global energy demand in the residential sector grew by 14% between 2000 and 2011; developing countries account for most of this growth [**2**]. Biomass and waste, electricity, natural gas and oil products are the main energy resources in the residential sector, collectively representing 90% of TFC in 2011[**3**]. In Algeria, the main fuel used in the building's heating space, is the natural gas, which can be used directly as a gas heater, or in a fired gas boilers, oil boilers and bottled gas can also be used. The use of renewable energy sources to provide a realistic alternative to fossil fuels and how much power can be obtained from all the various forms of energy? Can global warming be combated with the energy technologies currently available? Andrews, J [**4**] in his book Energy Science: Principles, Technologies, and Impacts enable the evaluation of the key sources of energy available to us today on the basis of sound, quantitative understanding. A detailed global review on energy consumption in residential sector, and its direct link to CO_2 emissions[**5**] and global warming is very important and an adequate policy should be taken to overcome the consequences.More informations about emissions scenarios can be found in ref.[**6**].The observed increase in the concentration of greenhouse gases (GHGs) since the preindustrial era has most likely committed the world to a warming of 2.4°C (1.4°C to 4.3°C) above the preindustrial surface temperatures. The committed warming is inferred from the most recent Intergovernmental Panel on Climate Change (IPCC) estimates of the greenhouse forcing and climate sensitivity. The estimated warming of 2.4°C is the equilibrium warming above preindustrial temperatures that the world will observe even if GHG concentrations are held fixed at their 2005 concentration levels but without any other anthropogenic forcing such as the cooling effect of aerosols. The range of 1.4°C to 4.3°C in the committed warming overlaps and surpasses the currently perceived threshold range of 1°C to 3°C for dangerous anthropogenic interference with many of the climate-tipping elements such as the summer arctic sea ice, Himalayan–Tibetan glaciers, and the Greenland Ice Sheet. IPCC models suggest that ≈25% (0.6°C) of the committed warming has been realized up to now[**7**].

Buildings are the environment where the majority of us spend most of our lives and they deeply influence many other consumption patterns and are an important factor in our life and comfort. The function and nature of buildings as they are currently constructed, accounts for many of the difficulties in moving towards sustainable consumption and production (SCP), both in present and in the future. Buildings have a long lifetime. This domain is a major target for any structural change in consumption patterns [**8**].

Energy use in the residential sector is defined as the energy consumed by households, excluding transportation uses. In the residential sector, energy is used for equipment and to provide heating, cooling, lighting, water heating, and other household demands. All of energy consumption, income, and energy prices affect the way energy is consumed in the residential sector. However, residential energy use is affected by factors such as location, building and household characteristics, weather, type and efficiency of equipment, energy access, availability of energy sources, and energy-related policies. As a result, the type and amount of energy use by households can vary widely within and across regions and countries. Residential buildings have continuously improved in efficiency. Though materials with better thermal properties and more efficient systems have lowered energy consumption for space heating in recent decades, substantial differences in energy consumption are still being observed in similar dwellings. World residential delivered energy consumption increases by 57% from 2010 to 2040 [**9**].

The population is expected to increase by 2.5 billion people by 2050, with the development of living standards and improvement in economics, the energy consumption in the building sector is expected to rise sharply, making additional pressure on the energy system. For some poor and energy sourceless countries, the price of energy is very high, when compared to the mean income, and most of the population cannot afford the space heating charges during cold season. For this kind of category of people, the reduction of energy consumption is more vital than for those who care about global warming climate.

Since the energy crises of 1973, most of the world countries started thinking about strategies and policies to reduce the energy consumption in all sectors and activities, the first driving raison was purely economic, environmental reasons were added later on, during this crisis, legislative texts regulating the use of energy, and the automatisation of systems consuming energy in all kind of activities. Most of the building regulations all over the world started during that period of crisis.

- The strategy used by the policy makers was at first to vote laws that regulate the energy use in different sectors, the building regulations have been applied for newly constructed houses in Europe, and other regulations were proposed for existing buildings. These building codes and standards need supporting executive orders to be applied.
- To achieve these goals, creation of incentives to sweeten the rational use of energy, and setting penalties for excessive consumption [example law May 2005 in Algeria].
- Encourage architects and builders to design sustainable buildings that are environmental friendly and cost effective, by using sustainable building materials with law embedded energy, and high thermal performance, and available on site like soil, and which reduces the transport cost and CO_2 emissions produced during the transport of materials.
- The maximum use of isolating materials for all the building envelope to reduce the heat loss, this should include the isolation of roofs and external walls and floors, and the use of double or trebled glazing windows, as well as the use of high quality doors that do reduce air infiltration to its maximum.
- The use of sustainable energy, and the search of natural ways to heat and cool as much as possible, by using the high technologies in the field of renewable energy, such as CHP solar unit, and the use of geothermal energy, solar, energy, and wind energy.

The main target of the Doctoral thesis is to find the"Optimal retrofit model to reduce the energy consumption in multi-apartment dwelling buildings". The first chapter is covering the energy consumption, with emphasis on residential building, in the world, Europe, and in Algeria. The second chapter reviews the residential energy consumption simulation software programs, furthermore latvian energy audit as well as other programs are discussed.The use of the energy audit program called energoaudits.eu and adapted by Latvian standard LVS EN ISO 13790/2009 [**10**] which is a program that enables the calculation of the energy performance of the building, and to calculate the feasibility of energy actions like insulations, replacement of windows, boilers, is discussedand a comparison between eQUEST and EnergyPlus is done,leading to the conclusion that eQUEST is more convenient as an early stage tool to evaluate energy consumption. In the third chapter an analysis of the residential energy consumption in Algeria is studied. In chapter four and on the basis of data collected from the Latvian utility services, a comparison of heat space energy consumption for two multi-family residential buildings during the period 2010-2013 is performed in chapter 4.

Top down and bottom up models for residential building, and their advantages and inconviniients are reviewed in chapter 5.Based on the simulation results, a heating energy consumption renovation strategy is developed in chapter 6 and a novel model of building envelope has been chosen, and a complex approch for optimal multi-apartment dwelling buildings has been achieved taking into account the insulation type and thickness as well the categories of glazing and their types, and as fixedby the target of the thesis, a new combined model (scenario) is applied, and 25% of energy is saved. The seventh chapter resumes the work presented followed by general conclusions.

REVIEWof ENERGY CONSUMPTION

1.1 World energy consumption

The unlimited increase of energy consumption in the world and its demand, caused by the increases of economical growth of both, developed and developing countries, brings economists and policy makers to think about means to reduce this increasing consumption. According to the energy outlook 2035 insights, the consumption of different fuel types, from1965 to 2035 is expected to increase by 27.5% for oil, 26.4 % for gas, 26.8% for coal, 4.9% for nuclear, 7.2 for hydro, and 7.2 for renewable energies. The world energy conception of energy in 1990 was about 1 million gigawatts, and now is approaching 10 million Gigawatts, this tenfold increase in one century is the product of threefold increase in world population and roughly threefold increase in average per capita use. The increase in per capita energy use is linked to the growth of the world economy [**11**]. A projection of the future energy consumption is very important for the analysis of energy economics and environmental policies. The world energy consumption long-term annual projection, according to the Energy Information Administration EIA 2013 about the international energy outlook projection is summarized in in table 1.1.

Since 1973 during the energy crisis, after the war of Israel and Arabs countries, a rationalisation of energy consumption and use, was strongly adapted, in all sectors, in industry, in transport, in agriculture, and in residential, by introducing automatic control techniques in industrial processes and making norms and standards for energy regulations in buildings and other sectors. The research to reduce energy consumption and its effects on climate is more than a must, starting from introducing new technologies in industry to reduce its energy consumption in different steps, or to improve the quality of existing materials in order to use less energy. Development of modelling and simulation programs of energy efficiency and consumption, to help architects, engineer, to choose the most efficient systems that consume less energy and produce less carbon dioxide.

The global-mean temperature and sea level rise would continue due to oceanic thermal inertia, even if atmospheric composition were fixed today. These constant-composition (CC) commitments and their uncertainties are quantified. Constant-emissions (CE) commitments are also considered. The CC warming commitment could exceed 1°C. The CE warming commitment is 2° to 6°C by the year 2040. For sea level rise, the CC commitment is 10 centimeters per century (extreme range approximately 1 to 30 centimeters per century) and the CE commitment is 25 centimeters per century (7 to 50 centimeters per century). Avoiding these changes requires, eventually, a reduction in emissions to substantially below present levels. For sea level rise, a substantial long-term commitment may be impossible to avoid [**12**].

On the other hand, the impact of the use of fossil fuel and other fuels, in increasing the CO2 emissions and its direct effect on the environment and climate conditions, and in participating with a great deal in the global warming is very important. Despite all these measures, the total energy consumption all over the world did not cease to increase. The world energy oil consumption increased sharply from 7000 TWh to 14000 TWh between 1965 and 1978, and then and due to the energy crisis, slow down until 1985, then it restart rising but not with the same rate as before.

Table 1.1 World energy consumption by country 2010-2040 (10^{10} kWh)

Region	2010	2015	2020	2025	2030	2035	2040	Average annual percentage change 2010-2040
OECD	7.09	7.15	7.47	7.70	7.88	8.05	8.35	0.5
Americas	3.51	3.54	3.69	3.80	3.89	4.01	4.22	0.6
Europe	2.40	2.40	2.49	2.60	2.66	2.72	2.78	0.5
Asia	1.17	1.20	1.26	1.28	1.31	1.34	1.34	0.5
Non-OECD	8.26	9.61	10.99	12.25	13.48	14.68	15.67	2.2
Europe and Eurasia	1.37	1.46	1.55	1.67	1.78	1.90	1.96	1.2
Asia	4.65	5.68	6.74	7.67	8.49	9.29	9.87	2.5
Middle East	0.82	0.96	1.084	1.14	1.40	1.34	1.43	1.9
Africa	0.55	0.58	0.64	0.70	0.79	0.90	1.02	2.1
Central and South America	0.84	0.90	0.96	1.02	1.14	1.23	1.37	1.6
World	15.35	16.7	18.46	19.92	21.36	22.77	24.03	1.5

Natural gas and coal keep rising almost with the same shape as for oil, but hydro and renewable nearly keep constant value from 1965 to 2000, where both start rising with a very slow rate, and this is due to the encouragement of the use of renewable energy all over the world. The United States maintains the biggest volume of demand for energy, but its relative share is decreasing over time from 24% to 19.8% for the expected period between 2010 and 2050. Japan demand in oil had a share of 31.5% in the global market in 2010, expected to be 27.7 in 2030 and 24.8 in 2050. Although the predicted energy consumption in USA, Japan, Europe, and most of the developed countries is decreasing, the total energy consumption is increasing significantly from [1.58168e+14 kWh] in 2010 to [5.18698e+14 kWh] in 2050. China growing economy consumed [4.1868e+13 kWh] in 2010, and expected to consume [1.50027e+14 kWh] by the year 2050.

1.2 World residential sector energy consumption

The whole world, developing and developed countries should be concerned with greenhouse gas emissions, sometimes the developing countries contested because the majority of developed countries are not fulfilling their commitment in the climate convention. For instance, of those countries, only UK and Germany reduced their emissions from 1996 to 2000, nevertheless, there is a consensus in the scientific committee of the Intergovernmental Panel on Climate Change, that all countries may be potentially affected by climate change, and the time required to reverse the increasing concentration of CO_2 from the atmosphere is great [**13**].

If current greenhouse gas (GHG) concentrations remain constant, the world would be committed to several centuries of increasing global mean temperatures and sea level rise [**7**]. Yet long-lived energy and transportation infrastructure now operating can be expected to contribute substantial CO_2emissions over the next 50 years [**14**].

Emissions scenarios such as those produced by the Intergovernmental Panel on Climate Change (IPCC) rely on projected changes in population, economic growth, energy demand, and the carbon intensity of energy over time [**6**]. Although these scenarios represent plausible future emissions trends, the infrastructural inertia of emissions at any point in time is not explicitly quantified [**15**] presented scenarios reflecting direct emissions from existing energy and transportation infrastructure, along with climate model results showing the warming commitment of these emissions. Contributions of past and present human generations to committed warming caused by cabon dioxide is developed in reference [**16**], Influence of socioecenomic inertia and uncertainity on optimal CO2 emissions abatment is explained in reference [**14**]. Energy consumption is an important component of the global climate change debate because much of the world`s anthropogenic greenhouse gas emissions relate carbon dioxide emissions. World energy related carbon dioxide emissions increase from 31.2 billion metric tons in 2010 to 36.4 billion metric tons in 2020 and 45.5 billion metric tons in 2040 table1.2. Table 1.2 shows the OECD and non-OECD energy related carbon dioxide emissions by fuel type, 1990-2040 (billion metric tons) [**3**].

In 2003 China emitted an estimated 3.5Gt of CO_2, compared with 5.8Gt by the United State, but by 2010 China had increased the emissions to 8.95 Gt, whereas those of the Unite States had decreased to 5.25Gt, though China`s per capita emissions are still 2.5 times less than those of the USA table 3[**4**].

Table 1.2 OECD and non-OECD energy related carbon dioxide emissions by fuel type, 1990-2040 (billion metric tons) [**3**]

Region/Country	1990	2010	2020	2030	2040	Average annual Percent change 2010-2040
OECD	11.6	13.1	13.0	13.4	13.9	0.2
Liquid fuels	5.5	5.85.8	5.7	5.6	5.7	-0.1
Natural gas	2.0	3.0	3.4	3.7	4.1	1.1
Coal	4.1	4.2	4.0	4.0	4.0	-0.2
Non-OECD	9.8	18.1	23.4	28.1	31.6	1.9
Liquid fuels	3.6	5.4	6.6	7.7	9.0	1.7
Natural gas	2.0	3.2	3.8	4.9	6.0	2.2
Coal	4.2	9.6	4.2	9.6	13.0	15.5
World total	1.821.5	31.2	36.4	41.5	45.5	1.3

Table 1.3 Carbon dioxide emissions in 2010 (Mton CO_2) and per capita emissions 1990-2010(ton of CO_2 per person)(include cement productions which counts 8% of global total CO_2 emissions [**17**].

Table 1.3 Carbon dioxide emissions in 2010(Mton CO_2)

Region/Country	CO_2emissions 2010Mt	Per capita CO_2 emissions			Change since 1990%	
		1990	2000	2010	CO_2	Population
United States	5250	19.17	20.8	16.9	5	23
EU-27	4050	9.2	8.5	8.1	-7	6
Russian Federation	1750	16.5	11.3	12.2	-28	-4
Japan	1160	9.5	10.1	9.2	0	4
Australia	400	16.0	18.6	18.0	46	30
Canada	540	16.2	17.9	15.8	20	23
China	8950	2.2	2.9	6.8	2.57	17
India	1840	0.8	1.0	1.5	180	40
South Korea	590	5.9	9.7	12.3	134	12
Indonesia	470	0.9	1.4	1.9	194	30
Brazil	430	1.5	2.0	2.2	96	30
Mexico	430	3.7	3.8	3.8	39	35
Saudi Arabia	430	10.2	12.9	15.6	159	70

1.3 Energy consumption by sectors of activity

According to the Energy Information Administration EIA data 2012, the world energy consumption in industrial sector have a share of 51.7%, followed by transport sector with a share of 26.6%, The residential sector with 13.9%, and the commercial with a share of 7.8%. In 1994, the final energy consumption of household had a share of 42%, followed by industry with a share of 31%, transport sector with a share of 22%, and non energy with a share of 5%. Figure1.1

EIA`s portfolio of data collections includes three surveys of energy consuming end use sectors: the commercial building energy consumption survey CBECS, the residential energy consumption survey RECS, and the manufacturing energy consumption survey. Prior to 1994, EIA also conducted a transportation energy use survey, the residential transportation energy consumption survey, but budget cuts forced this data collection to be discontinued after 1994 [**3**].

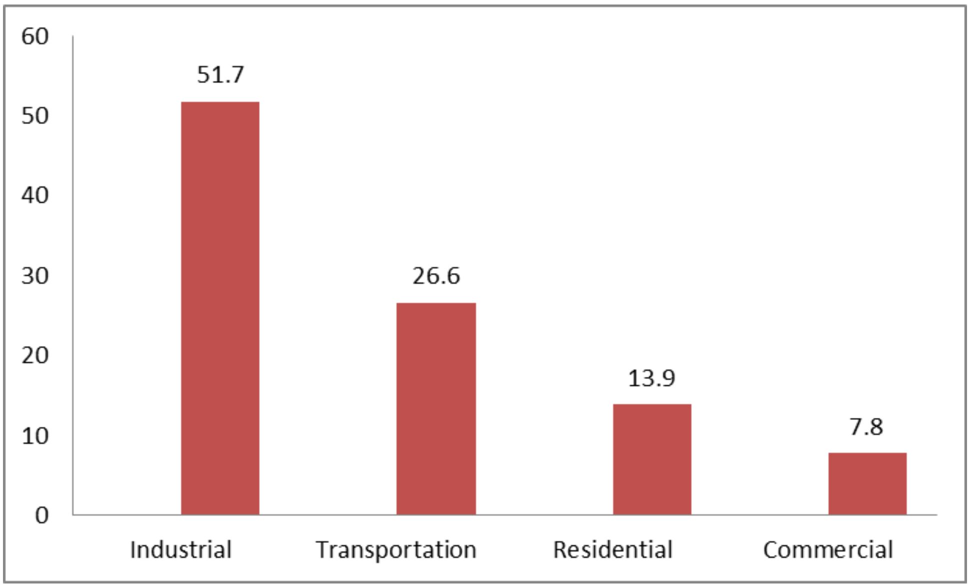

Figure 1.1 World energy consumption by sectors 2012.

1.4 World Energy consumption in residential and commercial buildings

Buildings are environments where we spend most of our lives, especially in cold climate region. Energy use in houses and other buildings is a significant proportion of energy consumption, set to rise with increase in population and the number of associated buildings, notably houses [**13**]. The building sector is defined as places where people reside, work, or buy goods and services, and the energy consumed in these places is residential consumption, some authors prefer to use the term residential only for places where people reside, and they use the term tertiary for places such schools, hospitals, or public offices. Industrial facilities used for producing, processing or assembling goods are excluded. In 2010, the building sector accounted for more than one fifth of total worldwide consumption or delivered energy. [**9**]

In order to reduce energy consumption and reducing the increasing CO_2 emissions, many governments have introduced building regulations for energy efficiency by acting upon different technical and political measures, such us the improvement of insulation of the building`s envelope, improvement of the building services equipment, HVAC, DHW, lighting, etc., and introducing laws and policies that help in reducing residential consumption. Despite all these measures, according to [**18-19**], energy-savings designs do not always result in the expected energy consumption. Residential buildings have continuously improved in efficiency. The use of the improved building envelope insulation and the infiltaration rate may affect the indoor air quality and thermal comfort [**20**]. Though materials with better thermal properties and more efficient systems have lowered energy consumption for space heating in recent decades, substantial differences in energy consumption are still being observed in similar dwellings [**21-22**]. World residential delivered energy consumption increases by 57% from 2010 to 2040 Table 1.4.

Table 1.4 Residential sector energy consumption 2010-2040 quadrillion Wh

Region	2010	2015	2020	2025	2030	2035	2040	Average annual percent change 2010 -2040
OECD	8.27	8.24	8.241	8.77	9.03	9.18	9.38	0.4
Americas	3.87	3.75	3.78	3.87	3.95	4.08	4.16	0.3
Europe	3.27	3.49	3.66	3.84	3.95	4.02	4.08	0.6
Asia	3.3	3.4	3.5	3.7	3.8	3.8	3.9	0.5
Non-OECD	7.00	7.91	8.79	10.26	11.73	13.19	14.60	2.5
Europe & Eurasia	1.8	1.8	1.9	2.1	2.2	2.4	2.5	1.0
Asia	3.10	3.75	4.57	5.48	6.51	7.59	8.68	3.5
Middle East	0.99	1.14	1.23	1.29	1.34	1.37	1.40	1.2
Africa	0.46	0.49	0.55	0.64	0.73	0.92	0.94	2.4
Central & South America	0.58	0.67	0.70	0.79	0.87	0.99	1.08	2.1
World	15.25	16.16	17.53	19.06	20.76	22.37	23.99	1.5

In the commercial sector, energy consumption focuses on heating and cooling systems, lights, water heaters, and other equipment in businesses buildings, institutions and other organisations. Schools, retail stores, restaurants, hostels, hospitals, office buildings, and leisure and recreational facilities can be as examples of commercial sector buildings [**23**]. The commercial sector included some non-building energy use contributes to such public services and water and sewer systems. Total world delivered commercial sector energy consumption grows at an average annual rate of 1.8% from 2010 to 2040, making it the fastest growing demand sector Table 1.5[**9**].

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Table 1.5 Total world delivered commercial sector energy consumption grows at an average annual rate of 1.8% from 2010 to 2040

Region	2010	2015	2020	2025	2030	2035	2040	Average annual percent change 2010-2040
OECD	20.2	20.9	22.0	23.2	24.4	25.5	26.5	0.9
Americas	9.8	10.1	10.5	10.9	11.5	12.0	12.6	0.8
Europe	6.5	6.9	7.4	7.8	8.3	8.6	9.0	1.1
Asia	3.9	3.9	4.2	4.4	4.6	4.8	5.0	0.8
Non-OECD	8.8	8.9	11.7	13.9	16.5	19.4	22.5	3.2
Europe and Eurasia	2.2	2.3	2.5	2.8	3.1	3.5	3.8	1.8
Asia	4.2	4.9	6.0	7.4	9.1	11.0	13.1	3.9
Middle East	1.0	1.1	1.3	1.5	1.8	2.0	2.4	3.1
Africa	0.4	0.5	0.6	0.7	0.8	1.0	1.2	3.5
Central and South America	1.0	1.1	1.3	1.5	1.8	2.0	2.4	3.1
World	28.9	30.8	33.6	37.1	40.9	44.8	49.0	1.8

As population grew and advanced economically and socially, it became more apparent that more intensive and more portable energy sources would be needed to support wide-scale mechanization, thus industrial promotion is a major priority for the governments of nearly all countries. All industrial developments require use of natural resources, many of which are limited, such as water, and so can directly affect local ecosystems. Industrial development can make significant beneficial contributions to country`s overall economic development by providing jobs, promoting socio-economic infrastructure and so on, however by its nature, industrial development can also have profound impact on environment. Energy consumption by the industrial sector is expected to grow from 58.659 quadrillion Wh in 2010 to 90.04 quadrillion Wh in 2040, increasing by an average of 1.4% per year. Most of the long-term growth in industrial sector delivered energy consumption occurs in the non-OECD countries.

Table 1.6 Industrial sector energy consumption 2010-2040 quadrillion Wh

Region	2010	2015	2020	2025	2035	2040	Average annual percent change	
							1990-2010	2010-2040
OECD	21.09	21.38	22.73	23.47	24.10	24.75	25.54	0.6
Petroleum and other liquids	8.03	8.06	8.59	8.88	9.12	9.29	9.56	0.6
Natural gas	5.58	5.92	6.36	6.65	6.89	7.12	7.39	0.9
Coal	2.55	2.55	2.63	2.69	2.69	2.69	2.69	0.2
Electricity	3.22	3.31	3.51	3.63	3.69	3.78	3.87	0.6

R.E.	1.55	1.52	1.61	1.67	1.75	1.84	2.05	0.9
Non-OECD	35.57	43.55	49.52	54.55	59.04	62.56	64.46	1.8
Petroleum and other liquids	8.74	9.55	10.83	11.52	12.61	13.57	14.45	1.7
Natural gas	7.62	8.38	9.52	10.60	11.68	12.73	13.60	2.0
Coal	12.90	15.47	17.83	19.56	20.72	21.19	20.55	1.6
Electricity	5.31	6.69	8.00	9.02	9.90	10.54	10.74	2.4
renewables	2.89	2.86	3.18	3.50	3.88	4.32	4.85	1.7
World	58.39	66.38	72.02	77.77	82.76	86.97	89.59	1.4
Petroleum and other liquids	16.70	17.98	19.39	20.47	21.66	22.83	23.97	1.2
Natural gas	13.28	14.25	15.85	17.22	18.51	19.79	20.93	1.5
Coal	15.44	18.01	20.47	22.25	23.41	23.91	23.24	1.4
Electricity	8.52	9.98	11.50	12.64	13.58	14.31	14.60	1.8
RE	4.44	4.38	4.82	5.17	5.61	6.16	6.86	1.5

1.5 Energy consumption in EU building sector

Most of the existed building stock in European countries is relatively old, and nearly 70% of the buildings have been built before 1980, the situation in Eastern Europe is even more dramatic but is somewhat improving very slowly [**24**]. The major part of the energy is lost in heating the old non renovated buildings, which consume up to 4 times as much energy as new buildings, this might give a big opportunity to save energy and to improve the building`s retrofitting. This retrofitting should be done correctly such as it can last at least 30 years. [**24**]. The build environment in Europe consumes 40% of the produced energy. In 2010, buildings consume 41% of final energy consumption in Europe, it is the largest end use sector, followed by transport 32%, and industry 25%, residential buildings in EU represent 76% of the of the building floor surface, of which 65% for houses owned by a single family[**25**]. The major part 75% of this energy is consumed in residential buildings. Houses and flats account for about 30% of the total energy consumed in the building in OECD countries [**26**]. Almost 30% to 57% of the consumed energy by household is spent on space heating and domestic hot water, it is very important to conserve energy in this area [**25**]. Annual unit consumption per m^2 for building at EU is around 220 kWh/m^2, in 2009, with a large gap between residential 200kWh/m^2 and non-residential around 300 kWh/m^2 [**27**]. Among the growing effort to create sustainable development strategies, a major part of the research focuses on energy related issues in the built environment [**23**].

1.6 Evolution of energy consumption in EU building

The energy consumption in building sector represented 41% of final energy consumption at EU level in 2010, in 1990 it was 37%, The residential sector have a share of 27%, which is close to 2/3 of the total energy use in the building, 14% for the tertiary sector[**27**]. The building consumption distribution between residential and non-residential depends on the country, in most of EU countries; residential buildings represent more than 60% of buildings energy use. This percentage is above 70% for Latvia, UK, or Poland, and even reaches 80% in Romania. The total heating space floor area represents 24 billion m^2 in the EU, 75% of this area is for residential. Apartments have a share of 35%, while single-family houses have a share of 65% of residential floor area. The average floor area in Europe is around 87 m^2 per dwelling (2009). The trend of the buildings permits in residential and non-residential sector, decreases between 2000-2002by 3% and 5% respectively then increases between2002 and 2007, and then dramatically decreases. An average of a 17 countries at the EU level shows that the annual unit consumption per m^2 in 2009, with a big difference between residential 200kWh/m^2 and non-residential buildings 295 kWh/m^2, the unit consumption is smaller in Spain, Bulgaria compared to Poland, Finland, and Estonia.

The dominant source of energy for households in EU is the natural gas with a share of 39% of the market, followed by the electricity, which is increasing rapidly from 19% in 1990, to 25% in 2009. Oil consumption is decreasing from 22% to 15% from 1990 to 2009. The following table (table 1.7) resumes the EU household consumption between 1990 and 2009.

Table 1.7 Household energy consumption by energy source in EU

	1990	2000	2009
Coal %	12	3	3
Oil %	22	20	15
Gas %	29	38	39
Heat %	10	8	7
Wood %	8	10	11
Electricity %	19	21	25

The percentage of wood grew from 8 to 11% for the period 1990 to 2009, coal percentage decreased from 12% to 3%, heat supplied by district heating represents only 8% of the total need, but it plays an important role in some of the northern countries such as Latvia, Estonia, Finland, and others.

Residential energy consumption in the EU is decreasing, the trend continued until 2010, while the residential electricity consumption is still raising, between 2005 and 2010, the growth rate was 1.69%, the number of appliances is rising, and they are getting more efficient. From 1990 to 2010 the consumption level of electricity by households in the EU-27 reached the highest level since 1990, (842.663TWh), in 1990 residential electrical consumption was 603.692 TWh, in 1999 it was 708.167 TWh, and in 2004 it was 786.625 TWh. The policies of energy efficiency in the white appliances sector were successful, and this is due to the combination of the EU legislation (energy labelling and minimum energy performance standards, national programmes (In Italy tax deduction, in Spain price rebate, scrapping bonus in Austria, and white certificate for cold appliances in France). The ENERGY STAR programme which is used for the electricity consumption of new office equipments sold in the EU in the last three years would have been approx. 67TWh, the programme succeeded in reducing this 11TWh, which means that this have saved EUR 1.8 billion saved on energy and 3.7Mt of CO_2.

1.7 Algeria European and International energy cooperation

The geographical position of Algeria is very important, it is a link between south and north, Africa and Europe, and between western Arab countries and eastern Arab countries, Algeria has a very large international energy cooperation with Asian countries (China 2004, South Corea 2006, Indonesia 2008), with American countries (Venezuela 2007, Peru 2005, Chili 2005) while the most important energy cooperation was established with European countries, and the European Union. Figure 1.2 shows the pipelines connections between Algeria and Spain through Morocco, and between Algeria to Italy through Tunisia [**28**].

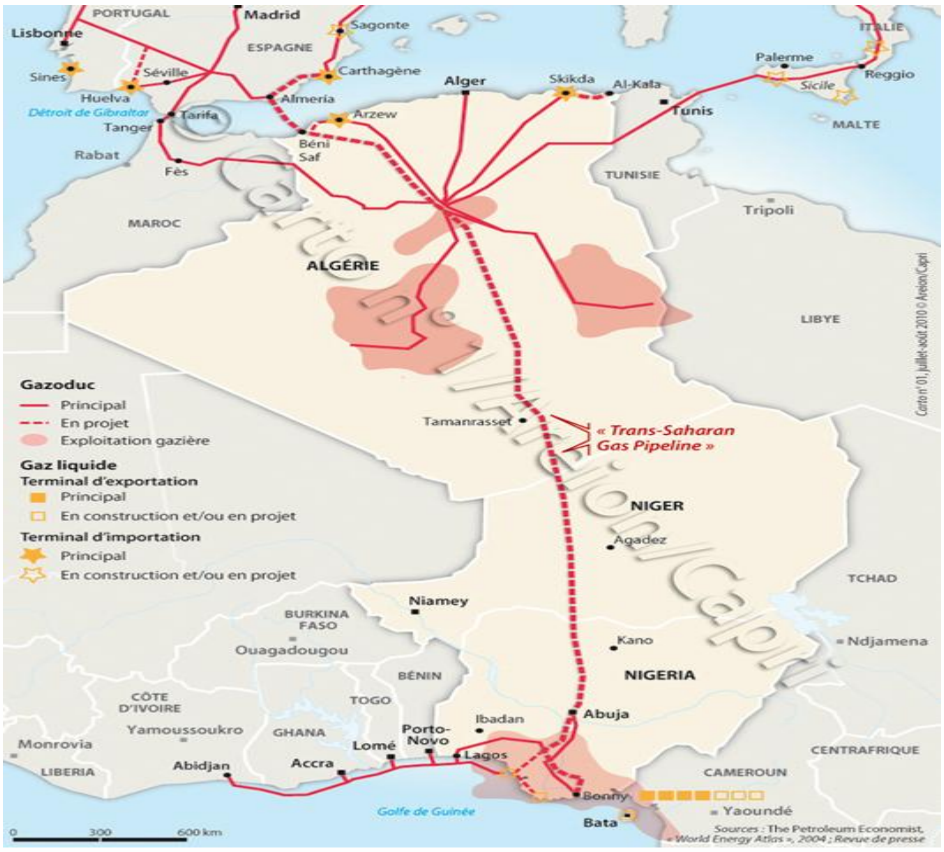

Figure 1.2 Pipelines from Algeria to Western Europe [**28**].

An important meeting was held in Algiers, on May 24, 2016, between EU and Algeria Business Forum dedicated to energy, and co-chaired by the Minister of Energy of the Democratic Republic of Algeria, Mr. Salah Khebri, and the European Commissioner for Climate Action and Energy, Mr. Miguel Arias Cañete. The organization of this forum is part of the strategic partnership in the field of energy, which occupies a central place in relations between Algeria and the European Union. The primary objective of this partnership was the development and the strengthening of cooperation between Algeria and the EU both in the hydrocarbon sector, particularly natural gas, as well as in renewable energy and energy efficiency. It also helps to facilitate and promote european investment in the sectors of natural gas, renewable energy and energy efficiency. [**29**]

To achieve these objectives, the Forum brought together public institutions, regulators, industrial and financial operators, business organizations and experts to analyse the prospects of investment in oil and gas, electrical energy, including renewable and energy efficiency, analyse the constraints and barriers to investment and, where appropriate, to identify the business environment improvement measures and to create a favourable environment for companies wishing to invest in energy sectors of Algeria and the EU.

In this context, the European Commission announced that they would fund up to 10 million Euros, in a program of technical assistance and support to the implementation of the National Program for Renewable Energy (PNER) and national programme for energy efficiency (PNEE). The commissioner for Climate Action and Energy, Miguel Arias Cañete declared to the press: "*Algeria is a very important partner for the EU and I welcome the strengthening and deepening of our very positive relationship. The Strategic Partnership between the EU and Algeria in the field of energy is a strong partnership based on mutual trust and mutual benefit, and we want to develop it further and include it in the long term. I hope that today's Forum, with its frank exchanges and constructive, will advance measures to improve the regulatory framework and the business environment in order to enhance the attractiveness of Algeria for European investors"*.

Dr. Khebri, Minister for Energy in his response to the commissioner for Climate Action and Energy, declared the following: "*Relations between Algeria and the European Union are strong, particularly in the energy field. Today's meeting is to further strengthen these relations. The dynamic deployment of our cooperation to be effective and lead concrete and tangible results, has to involve businesses and economic operators of both sides this meeting is designed for this purpose to enable them to know, and to explore the various possibilities and forms of possible partnerships, identify respective needs and complementarities and build business relationships"*.[**29**].

Due to the commitment of the Algerian side and the strong interest shown by European industry, this forum has proved a great success. More than 500 European and Algerian companies and industry associations, financial institutions and experts participated and contributed to a rich debate, open and constructive. Many companies, including the major European oil and gas companies were represented at the highest level. A round table and two high-level thematic sessions enabled business leaders to discuss with the Algerian authorities the prospects of development of the natural gas sector, renewable energy and energy efficiency, as well as measures that could facilitate investment.

The forum also allowed the linking of the Algerian and the European companies, through Business-to-Business Session (B2B), which attracted a large number of participants (170 participating companies and over 500 B2B meetings). This B2B will be the starting point for the establishment of partnerships between Algerian and European companies and new investment projects. Other editions will follow this first forum. Both groups of experts on EU-Algeria gas and renewable energy and energy efficiency, already active since late 2015, will meet shortly to discuss and decide on further to the conclusions of the Forum and new shares cooperation to implement. Forum's conclusion, Commissioner Arias Cañete invited the Minister Khebri to go to Brussels on a date to be agreed upon, for a high-level political dialogue meeting that will assess progress completed in the implementation of the strategic energy partnership and guide future development.

1.7.1 Cooperation with Germany

Joint statement of intent for an energy partnership between Algeria and Germany, was signed March 26, 2015 in Berlin, the Minister of Energy, and the Vice-Chancellor and Federal Minister of Economics and the Energy, on the side-lines of the International Conference on Transition of Energy Dialogue “Berlin Energy Transition Dialogue”.This statement is aimed at strengthening bilateral relations in the energy field through the establishment of a high-level dialogue on the various themes of energy policy, such as the diversification of the energy mix, the development of renewable energy, the improving energy efficiency and environmental protection.[**30**]

1.7.2 Cooperation with Russia

Declaration of Algerian-Russian intention in the energy field, signed by the two energy ministers on the side-lines of the 21st World Petroleum Congress held in Moscow from 15 to 19 June 2014. It focuses on the development of cooperation in the fields of oil, electricity, renewable energy, energy efficiency and training. As part of the implementation of the recommendations of the Declaration of Algerian-Russian plan, a first meeting of the Algerian-Russian Working Group, held in Algiers April 19, 2016. Cooperation agreement in the field of using nuclear energy for peaceful purposes, signed September 3, 2014 on the occasion of the visit to Algeria by Mr Sergey Kiriyenko, CEO of Rosatom. [**30**]

1.7.3 Cooperation with UK

Cooperation Roadmap in the field of renewable energy and industrial safety signed by the energy ministers of the two countries during the visit of Minister of Energy and Mines in the UK March 2010.

1.7.4 European Union (EU)

A strategic partnership between Algeria and the European Union in the field of energy was signed in Algiers, July 7, 2013, by Mr. Abdelmalek SELLAL, Prime Minister and José Manuel Barroso, President of the European Commission during the memorandum of understanding on the establishment of a strategic partnership between Algeria and the European Union in the energy field. The Memorandum establishes a framework for cooperation covering all matters of common interest, namely hydrocarbons, renewable energy and energy efficiency, reform of the legislative and regulatory framework, the gradual integration of markets in energy, development of infrastructure of common interest, technology transfer and local development. As part of the implementation of this memorandum of understanding, an administrative arrangement was signed in Algiers on May 5, 2015, on the implementation of the terms of the strategic partnership between Algeria and the European Union in the field of energy. [**30**]

Algeria has a current population of 41029805, 80% of it lives in the northern part wich nearly 20% of the algerian land, and 20% lives and the southern part which represents 80% of the total land. The climate and the building style of the northen part of Algeria, is mediterranian, and it is the same climateas in southern european countries, Spain, France, Italy and Greece. The energy consumption trend in Algeria, from 2000 to 2015, and accoording to the energy data year book 2016, is in a constant increase, and it has doubled, starting from 27 Mtoe to for the year 2000 to 53 Mtoe. Owing to the measures taken according to the european energy directives and standards, the southern european countries such as Spain, France, and Italy (those who share with Algeria the mediterranian climate), have their total energy consumption nearly constant, or decreased. For Spain it increased between 2000 and 2005 from 122 to 143 then decreased to 116 in year 2015. For France , it increases for that same period from 255 to 271 then decreasres to 246 Mtoe. For Italy it follows the same trend as in France and Spain, from 172 Mtoe in 2000 to 184 in 2005and then to 152 in 2015.

1.7.5 International Agency for Renewable Energies (IRENA)

IRENA was established in 2009 aims to accelerate the use of renewable energies worldwide, especially in developing countries. The Agency's main task is to support the implementation of national strategies and to facilitate trade and access to information on renewable energies through North-South cooperation. It currently has 139 members, and 32 signatory countries in accession. Algeria has ratified the statute of IRENA December 30, 2011. [**30**]

1.7.6 The International Energy Forum (IEF)

The International Energy Forum (IEF) is the institutionalization of the "dialogue producer-consumer energy" started in the 1990s Its first meeting was held in Paris in 1991 at the initiative of France and Venezuela. Algeria is a member of the Executive Board since 2006. Since joining the board, Algeria was very active, as well, at the Joint Oil Data Initiative (JODI), ministerial conferences, by organizing meetings Algeria techniques include: Training on the JODI 3rd seminar for the MENA region, 2007.

Algeria is contributing concretely and supporting the development of the monthly statistics published by the Forum Secretariat. Algeria was also co-organizer with the Netherlands, the 13th Ministerial Forum hosted by Kuwait in March 2012.

1.7.7 African Energy Commission (AFREC)

The African Energy Commission (AFREC) is a structure of the African Union which was launched at the Conference organized African Energy Ministers held in Algiers on 23 and 24 April 2001.L'Algérie played an active role in the creation of this commission at the 37th Summit Conference of Heads of State and Government of Africa in Lusaka (Zambia) in July 2001 during which it was decided that its headquarters be established in Algiers. After obtaining the required number of ratifications, AFREC was officially launched in Algiers in February 2008. [**30**]

1.7.8. Arab and African Cooperation

a-agreements signed with Arab countries

Tunisia: Memorandum of understanding in the field of Renewable Energy and Energy Control, signed in Algiers in July 2009, on the occasion of the meeting of the Bilateral Energy Committee.

Kuwait: Memorandum of understanding in the field of Oil, Gas and New and Renewable Energies, signed in Kuwait in June 2010, on the margins of the Joint Committee 6th session Algerian-Kuwaiti.

Qatar: Memorandum of cooperation agreement in the field of oil and gas, signed in Algiers on January 7, 2013. This Memorandum of cooperation covers the development of cooperation between the two countries in the field of oil and gas. [**30**]

b- Agreements signed with African countries

Nigeria and Niger: In 3rd of July 2009, an agreement was signed in Abuja, the Nigerian capital, between Algeria, Niger and Nigeria, for the construction by 2015 of a gas pipeline across the Sahara. The idea was to convey, via Niger and Algerian desert, the Nigerian gas resources (Warri) to the Algerian ports. Connections to existing networks in Algeria are scheduled, which allow exporting the Nigerian gas to Europe. Nigeria's gas reserves are the seventh in the world (180,000 billion cubic meters), and the Niger Delta is closer to the centre of Europe that the Siberian deposits.

This proposed "Trans-Saharan Gas Pipeline" (TSGP) is part of the New Partnership for Africa's Development (NEPAD), launched in 2001 by the African Union in order to promote the establishment of an integrated socio-economic and strategic development of the entire African continent. With a total length of 4,300 kilometres (including 1300 in Nigeria, Niger and about 700 to 2300 Algerian territory), this pipeline will transport annually 20 to 30 billion cubic meters of natural gas. It will lead on the Mediterranean coast at Beni Saf to the western part of Algeria and Al-Kala for the eastern part of Algeria. Led by the Algerian public company Sonatrach and the National Petroleum Company of Nigeria, NNPC, the project interests the Russian Gazprom, French Total, Anglo-Dutch Shell and Italy's Eni. The amount is estimated at more than $ 21 billion.

The pipeline route is expexted to be lined to a highway Algiers-Abuja or Lagos-Algiers, as well as a fibre optic line. From an environmental point of view, the proponents insist on an underground route, ultimately reducing the impact on natural environment traversed, and the circumvention of the Sahara oases. [**28**]

Angola: Cooperation protocol in the field of Geology and Mines, signed in Luanda in March 2008, alongside the Commission 3èmesession Algerian-Angolan Joint.

Tanzania: Memorandum of cooperation agreement in the field of Energy and Mines, between Algeria and Tanzania, signed in Algiers, December 2, 2013, on the occasion of the visit to Algeria, from 25 November to 4 December 2013, the Tanzanian Minister of Energy and Mines.This MOU covers the development of cooperation between the two countries in the field of oil resources, mining and electricity.

Ethiopia: Memorandum of cooperation agreement in the field of mineral and petroleum resources, signed in Addis Ababa on 26 January 2014, on the occasion of the holding of the third session of the Algerian-Ethiopian Joint Commission.

This MOU covers the development of cooperation between the two countries in the field of oil resources, mining and electricity.Kenya: Memorandum of cooperation agreement in the field of Oil, Gas and Energy, between Algeria and Kenya, signed in Algiers on

February 25, 2015, on the occasion of the visit to Algeria of the President of the Republic of Kenya.This MOU covers the development of cooperation between the two countries in the field of oil, gas, electricity and renewable energy. [**30**]

1.8 Algerian energy consumption

The energy total final consumption (TFC) in 2007 reached 236.2 TWh for a 34.4 million inhabitants with 2 393 367 square km, and with Gross Domestic Product (GDP) equal to 9 389.70 million DA (Algerian Dinars) [**31**]. The consumption per capita, in Algeria is 12304.54 kWh per person, while for Morocco, which has nearly the same number of inhabitants is 5326.54 kWh and in Tunisia is 9804.09kWh. The total gas emission is equal to 46 millions of tonnes of CO_2 with an average of 3 $TECO_2$/TOE. The GDP is equal to 3.2322 billion of DA.

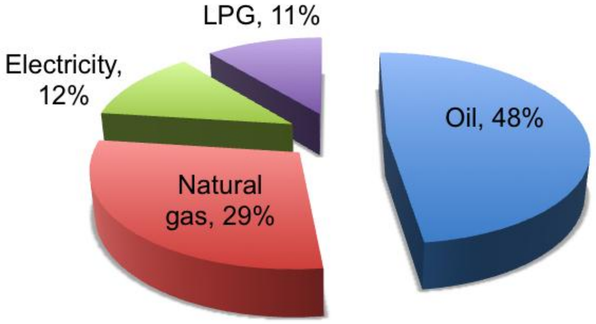

Figure 1.3 Energy consumption by fuel type

This is firstly due to fuel prices in Algeria, and probably due the level of average living standard and purchasing power, which is greater in Algeria than in its neighbouring countries. The portion population having access to electricity is, when writing this paper, and according to the World Bank, is 99.3 % for Algeria, 97% for Morocco, which counts nearly the same number of inhabitants. Thus, allowing the access of Algerian citizens to more electrical appliances such as air conditioning units, and refrigeration, TVs and so on, and natural gas appliances such as gas boiler for central heating and hot water, gas stove, and gas cooker. The percentage of population connected to electric power is 99.5%, in Tunisia, but consumption of natural gas in kWh per capita for year 2006, is 4801.98 while it is 9264.79 for Algeria, and 2155,5 for Morocco [**2**].

Total energy consumption distribution by fuel type shows (Figure 1.3) that oil is the most consumed fuel, shares are as follows: 48% share for oil products, 29 % share for natural gas, 12% for electricity, and 11% for LPG, GDP per inhabitant is equal to 93 959DA with an average consumption of 6757.03 kWh per inhabitant. Meanwhile the final gas emission is 1.83 $teCO_2$ and the primary emission is 2.222 $teCO_2$ per inhabitant. Sector shares in Total energy consumption are 7% for agriculture and hydraulics, 33% for transportation, 19% for industry (without hydrocarbons) and building construction, and 41% for residential and tertiary sector. The final energy consumption by type of fuel and by activity sector is shown in Table 1.8 The percentage of CO_2 emission in Algeria between 2009 and 2010 according to the global energy statistical yearbook [**17**] is 4.2% of the global emissions, which is less than African emission percentage for the same period 5.8%. The average annual growth rate in petroleum industry is 5.93%, and in gas industry is 4.84%, For this recorded rate, the average annual growth of agriculture and water resources, industry-building construction, residential - tertiary, and finally transport are given in the Table 1.8

Table 1.8 Average annual consumption growth in percentage

Agriculture and Water resources	Petrol industry	Gas industry	Industry and building construction	Residential and tertiary building	Transport
8.7%	5.93%	4.84%	6.46%	5.9%	5.76%

As it has been shown in the table 1.9, the percentage of the average growth in the residential and tertiary sector is merely the same as in petrol industry, the transport has an average less than in the petrol industry, whereas, both industry - building construction, and agriculture –water resources illustrate a percentage value more than that of the petrol industry. The total energy annual growth consumption counts for 321.75 gigaWh, therefore producing annual amount of 76.45 TCO_2. In his chapter, total energy consumption by activity and by type of fuel is analysed, starting with the industrial sector, the transport sector, and finally the agriculture sector followed by conclusions.

Table1.9 Energy consumption by type of fuel and by sector

TWh	Solids	Gasoline	Diesel	Heavy fuel	Light fuel	LPG	Natura l gas	Electricity	Total
Industry and construction	5,547	0	7,787	0	0	0,863	28,353	64,903	5,046
Residential	0	0	16,535	0	0,238	18,74	31,95	8,95	76,42
Tertiary	0	0	1,43	0	0	0,64	4,37	7,39	13,83
Transport	0	27,34	35,25	6,93	0	4,62	0	0,031	76,05

1.9 Algerian renewable energy perspectives

To provide comprehensive and sustainable solutions to environmental challenges and problems of preservation of fossil energy resources, Algeria launched an ambitious program for the development of renewable energy, which was adopted by the Government in February 2011 and revised in May 2015.

The projected program of renewable energy is to install a renewable power of around 22,000 MW by 2030 to be used for the national market, and with the maintenance of the export option as a strategic goal if possible.

The Algerian renewable energy program development intends to product electricity from photovoltaic and wind power by integrating biomass, cogeneration, geothermal and later beyond 2021 solar thermal.

These energy systems are the engines of sustainable economic development capable of driving a new model of economic growth. Over 37% of installed capacity by 2030 and 27% in electricity production for internal market consumption will be from renewable sources.

The national renewable energy potential is heavily dominated by solar; Algeria considers this energy as an opportunity and a social and economic development lever, especially through the implementation of industries creative of wealth and jobs.

The strategy of Algeria in this area is to develop a real renewable energy industry combined with a training program and knowledge capitalization, which will eventually employ Algerian local engineering, particularly in project management. The renewable energy program for electricity needs of the national market will create several thousand direct and indirect jobs.

1.9.1. Residential energy cost evolution 1994-2005

The electricity and gas bill for residential consumption is divided into two slices, the evolution of the price of the first slice jumped for 1 kWh, from simple to nearly double, (from 0.935 DZD (1DZD = 0.01296 USD) in June 95 to 1.779 DZD in April 2006,) for the second slice it jumped from 1.609 to 4.179 DZD, which is more than 2.5 times.

However, for natural gas with which most cities are fed, the unit price has risen from 0.149 DZD/unit for the first slice to 0.168 DZD/unit. Consumption up to 1125 units was considered first slice was until June 2006, when the utility company decided to reduce it from 1125units to 375 units, which means that the price of the first slide has not only risen from 0.149 to 0.324 DZD/unit, but also the number of unit consumed for the first slide which was 1125 has been reduced to 375units, making 750 units switched from first slice to second slice with a unit price of 0.324 DZD/unit, which results in more than tripling the cost. The unit price of the second slice (>1125) jumped from 0.01DZD/kWh to 0.011 DZD/kWh in just few months from June 2005 to April 2006, taxes followed nearly the same increase.

Since May 2005, the price of the energy was fixed by government decision published in the official journal of the Algerian republic. The first 125 kWh of electric energy consumed are charged at 1.779 DZD without taxes, the remaining are charged at 4.179 DZD kilowatt-hours without residential consumption taxes. Non-residential consumption is charged 4.179 DZD per kilowatt-hour without taxes.

The unit price of natural gas and electricity consumption was fixed according to the decision D/06-05/CD of May 30th, 2005. The difference between new and former meter index is multiplied by a coefficient, which is a function of temperature and altitude, and which is equal to 8.7 for Sétif area. The first 375 units are charged 0.0057 DZD /kWh, the rest at 0.011 DZD / kWh. Taxes for electricity consumption are charged on the basis of the amount of the energy consumed, those who consume less than 70 kWh, are exempted from the taxes E50 called fixed rights, consumption between 71 and 190 kWh is charged 25 DZD, from 191 to 390 is charged 50 DZD, consumption over 391 kWh is charged 100 DZD. Taxes called M99 are set by the finance act (Law 05-16 of December the 31, 2005) and depend on the amount of the invoice, void if the amount is less than 50 DZD, 0.5 DZD, if the amount is between 50 DZD and 500 DZD, for more than 500 DZD, each 100 DZD is charged 1 DZD with a maximum of 2500 DZD. VAT is fixed at 7% for consumption and 17% for delivery.

1.9.2 Energy consumption in residential building

Final energy consumption in residential buildings has reached the value of 75.59 gigaWh, in 2010, for almost 4.4 million housing units in urban areas, and 1.9 million housing units in rural areas, with an average number of occupancy of 6 persons per house. The household electrical equipment consumption accounts for 75% of the total electrical energy consumed in the dwellings, the remaining 25% are for lighting [**32**]. The average annual energy consumption of housing unit is 121.22kWh. Natural gas consumed in residential buildings represents 66%, petroleum products 22%, and electricity 12%. Power consumption of the residential sector reached 8955 kWh which represents 33% of the total electricity consumption, and 5070.68kWh in gas, which represents 70% of total gaseous products[abdellah zerroug construction science]. Figure 1.4 illustrates the residential energy consumption by type of fuel from year 2007 to 2013.

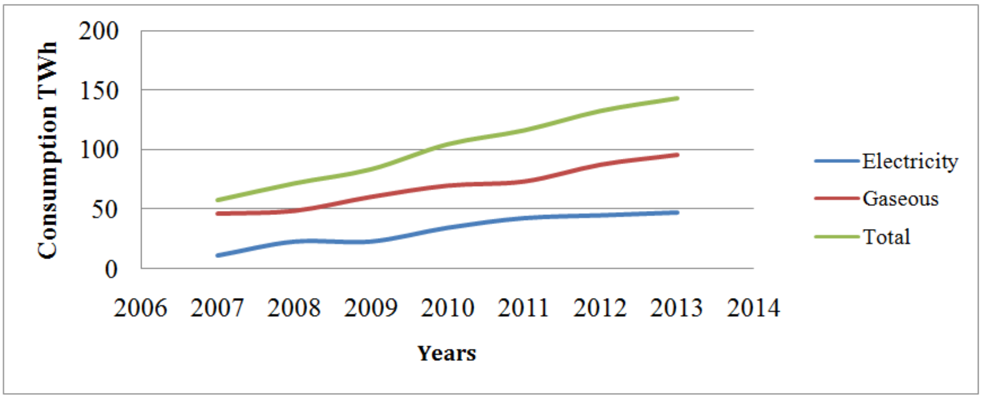

Figure 1.4 Residential energy consumption evolutions

1.9.3 Energy and environment

Emissions of greenhouse gases due to the final energy consumption reached 46 million TCO_2. The structure of consumption emissions by sector is given in table 1.10.

Table 1.10 CO2gas emissions by activity sector and fuel type

TCO_2/Toe	Electricity	Gaseous products	Petroleum products	Total products
Agriculture	0.133	10.369	2.826	13.329
Residential	0.269	1.526	0.658	2.454
Tertiary	1.229	0.834	0.310	2.372
Industrial	0.397	1.762	0.184	2.343
Petroleum industry	0.107	2.021	0.225	2.352
Transport	0.001	0.133	2.825	2.959
Total sectors	0.238	1.161	1.176	3.034

The total emissions balance sheet is 76 $MTCO_2$. 19 $MTCO_2$ is produced by transport and represents 25% of the emission, 16 $MTCO_2$is produced by industry and represents 21% of the emission, whereas 15 $MTCO_2$ is the results of agricultural activities and accounts for about 19% of the total emission. Oil industry has a share of 18% with a production of 13.5 $MTCO_2$, and finally the tertiary participates with 10% of total production of 7.6 $MTCO_2$.

According to the AIEA (Agence International de l'Energie Atomique) report for the year 2000, the annual total emission of an Algerian inhabitant is less than 1 TCO_2/inhabitant/year, and for African average is 3TCO_2/habitant/year, 6 for the French, 9 for the European, and 20 for the American. Emissions from final energy consumption are 46 million TCO_2 with a 1.830 of TCO_2 per capita, 3.235 of TCO_2 emissions for one Ton oil equivalent consumed. For one thousand Algerian dinars consumed only 0.020 ton of CO_2 emission is produced. Total emissions due to primary energy amount to 82.6 million TCO_2. 30% of this production is due to electricity generation, 35% is due to the gaseous products, and 35% due to petroleum products. The province of Setif has a central position with six thousand five hundred and fifty square kilometres (6550 km^2), and with a population of one million and six hundred thousand inhabitants, consume more than 5.4 % of the national production, and participates with 4.70% of National CO_2emission.

The Algerian Building regulations as in the executive decree 2000-90 of April, the 24th, 2000 and the law 99-9 of July the 28th, 1999, in its articles 11 and 12 gives the following directives, the new building owner or designer must be sure that the thermal characteristics of newly constructed buildings must have a buffer aginst heat loss by thermal transmission through the building envelope, and ventilation, as required by Document Technique Règlementaire (DTR).[**33**].As it has been shown from previous research results, that, the value of the overall heat transfer coefficient'a' in the recommended regulation, for external walls and roofs in contact with outdoor air, for attached or detached houses, is bigger than the reference by 70% for climatic zone A, 48% for climatic zone B, and 100% for climatic zone C, with an overall average percentage of 73%. For floors, the overall heat transfer is more than the reference, by 5% for climatic zone A, -0.1% for climatic zone B, and 8% more for Zone C, with an average increase of 2.9%. The overall averages percentage for walls, doors, and windows are respectively equal to 1.23%, 12.62%, and 0%.

The mean overall coefficient for all type of flats, in climatic zone A, for external walls, including roofs, was found to be 9.7% more than the reference value. For zone B it was found to be 21%, and for zone C 43%. While the same coefficient for floors was found to be 7.9% more in zone A, 4.1% more in zone B, and 7.5% more in zone C. Coefficient c and e, which represent the overall coefficient for walls, and doors remain the same without any variation recorded. For the d coefficient, which represents the heat transmission through the unit windows/door-windows, was greater than the reference value by 1.43% for climatic zone A, 4.28 % for climatic zone B, and 3.43% for climatic zone C.

These results show very clearly that the thermal regulation recommended by the DTR (coefficients a, b, c, d, and e) are far away to be respected in the surveyed houses and flats.

The external envelope of buildings needs to be more insulated, and DTR recommendations should be respected. More decisions for the application of the regulation should be taken before the final reception of –at least- for government projects. Regulation itself should be updated; it seems that this regulation is the same as the French thermal regulation published after the 1973 oil crisis.The Algerian electrical energy consumption in buildings is more severe in summer time due to heavy cooling load. A district cooling system, especially in the southern part of Algeria, where cooling load is very expensive, could be a good alternative. Solar refrigeration using absorption systems to produce chilled water for district cooling in the southern part seems to be a good perspective.

1.10 Conclusion

The trend and shape of the world energy consumption is fundamental for sound economics and sustainability. Increase in energy demand, climate change, and limited fossil fuel resources will urge policy makers and decision makers to adjust their energy strategies and address future energy needs. Renewable energies should be introduced with more share in total final energy consumption, and substituted to the most polluting traditional energy sources, which are not only harmful to the environment but also are finite in the long term.

InEU, in the last decade, the residential sector energy consumption has started to decrease. The decreasing trend continued until the year 2010 when consumption grew again, between 2004 and 2009 total final residential energy consumption in the EU-27 fell down by a percentage of 2%, reaching the lowest consumption level of the last 20 years in 2007. Meanwhile, this very important decrease (-4% compared to 2006) in 2007 could be explained by the warm temperatures during this year that resulted in a lower number of heating degree days compared to the average heating days. Between the years 2005 to 2010, total final energy consumption in EU-27 decreased by -3.29%. The level of energy consumption of 2009 was nearly the same, as 10 years earlier. The total final energy consumption in EU-27 has increased by 3.25% since 1990. In year 2005, consumption increased and reached 138.397×10^5 TWh, then it started decreasing by -5.2% until 2008,%, but between 2009 and 2010 consumption increased by 3.56%.

The electricity consumption in residential sector kept still raising, between 2005 and 2010 the increase rate was 1.69%.

In the period 1990– 2010, total residential electricity consumption rose by 31.92%. In 2010 the consumption level of electricity by households in the EU-27 reached 842,663GWh, its biggest level since 20 years. In 1990 residential electricity consumption was 603,692 GWh, in 1999 it was 708,167 and in 2004 it was 786,625 GWh. Lighting energy consumption was estimated, in the residential sector to be 10.5% of total electricity consumption in 2007. In 2009, the percentage was estimated to be 10%. Energy efficiency in the white appliances sector has been found to be very successful.

The success might be due to the combination of EU legislation (energy labelling and energy performance standards, programmes (e.g. tax deduction in Italy, scrapping bonus for cold appliances in Austria, price rebate schemes in Spain, supplier obligations and carte blanche in France, Italy and the UK).

Since the Eco design regulations have been applied for cold appliances, washing machines and dish-washers, hobs and grills in June 2009, 15% of washing machines, 10% of dishwashers, 5% to 56% for cooling and freezer appliances were already better than energy class A (A+, A++, and A+++). More than 55.7% of fixed air conditioners sold in 2010, were A class appliances in eastern Europe, while it was 77.3% in western Europe in the same period. Total electrical consumption for TVs has increased between 2007 and 2009 by around 2-3% reaching a value of 56TWh. Among the fastest growing electricity end use in residential and non-residential, are Information and Communication Technologies.

Electrical energy consumption of new tertiary equipment sold in the EU in the last three years would have been approx. 67 TWh. But the successful ENERGY STAR Programme reduced this consumption by about 11TWh, which represents 16% of energy savings, 3.7Mt of avoided CO_2, and more than 1.8 billion EUR. And it is estimated that

ENERGY STAR will succeed by 2020 in reducing energy that would be consumed by the installed base of computers, displays and imaging equipment in the EU by more than 30%.During the last years, final energy consumption in the non-residential sector has been growing. In 1999, final total energy consumption in the sector in the EU-27 was 1436 TWh, meanwhile, in 2009 the sector consumed 1666.26 TWh and in 2010 the consumption level increased to reach the value of 1.77 TWh.Between 1991 and 2009 electricity consumption in the non-residential sector has increased by 66% in the EU-27.

In Algeria**,** The percentage of the average growth in the residential and tertiary sector is merely the same as in petrol industry, the transport has an average less than in the petrol industry, whereas, both industry - building construction, and agriculture –water resources illustrate a percentage value more than that of the petrol industry. The total energy annual growth consumption counts for 321.75gigaWh, therefore producing annual amount of 76.44 MTCO2. Total energy consumption distribution by fuel type shows that oil is the most consumed combustible, this is due to the growing industry demand and transport. The consumption of natural gas for industrial purposes, such as electricity production by thermal stations using natural gas, comes in second place because of the increasing demand in residential and tertiary, as well, as in energy-industry, and non-energy industry. The increasing demand for electricity represents 12%.

The Algerian Building regulations as in the executive decree 2000-90 of April, the 24th, 2000 and the law 99-9 of July the 28th, 1999, in its articles 11 and 12 give the following directives, the new building owner or designer must be sure that the thermal characteristics of newly constructed buildings must have protection against heat loss by thermal transmission through the building envelope, and ventilation, as required by DTR. But these directives are not followed by an executive decree, and, even newly built government projects, were found to be very far from the DTR recommendations.

These results of previous research show very clearly that the thermal regulation recommended by the DTR is far from being respected in the surveyed houses and flats.

The external envelope of buildings needs to be more insulated, and DTR recommendations should be respected. More decisions for the application of regulation should be taken before the final reception of at least government projects. The regulation itself should be revised, as it seems that this regulation is similar to the French thermal regulation published after the 1973 oil crisis

SIMULATION SOFTWARE PROGRAMS

2.1 Introduction

The use of the energy audit program called energoaudits.eu and adapted by standard LVS EN ISO 13790/2009 is a program that enables the calculation of energy performance of building, and the calculation of the feasibility of energy actions like insulations, replacement of windows, boilers etc.Building energy efficiency class is calculated according to the building characteristics introduced in the program. In this program, we need to input the following data, the building address, the average temperature, the heating source, the number of heated floors, the ground floor height, the ground floor perimeter, and the ventilation quality.For the heating sources we can choose one from the following: electricity, diesel, heat pump, wood pellets, firewood, wood chips, and heat from boiler house.For air exchange in buildings we have the choice to choose between the appropriate sealing according to the air circulation and the windows type, starting from:

1. Very good sealing, minimal air circulation, plastic windows.
2. Good sealing, small air circulation, plastic windows.
3. Satisfactory seal, medium air exchange, plastic windows.
4. Small air exchange felt , well old type windows.
5. Airflows felt, old type of windows.
6. At the windows felt airflows, old windows, and doors.

The wall's layers can be fitted but a small variety compared to other programs, the material of the sandwich wall can be chosen from the following: Rockwool, polystyrene insulation, hollow ceramic bricks, silicate bricks, word, eco aero blocks, keramz concrete, aerated concrete, fibro blocks, drywall, reinforced concrete, lime-sand plaster, silver concrete, granite, copper, air, and concrete. [**10**].

Windows characteristics are from the type of single glass, double plastic windows, and triple glass plastic window.The attic/roof material layers can be formed of Rockwell, polystyrene, wood, aerated concrete, drywall, reinforced concrete, lime –sand plaster, silver concrete, copper and air. Figure 2.1.

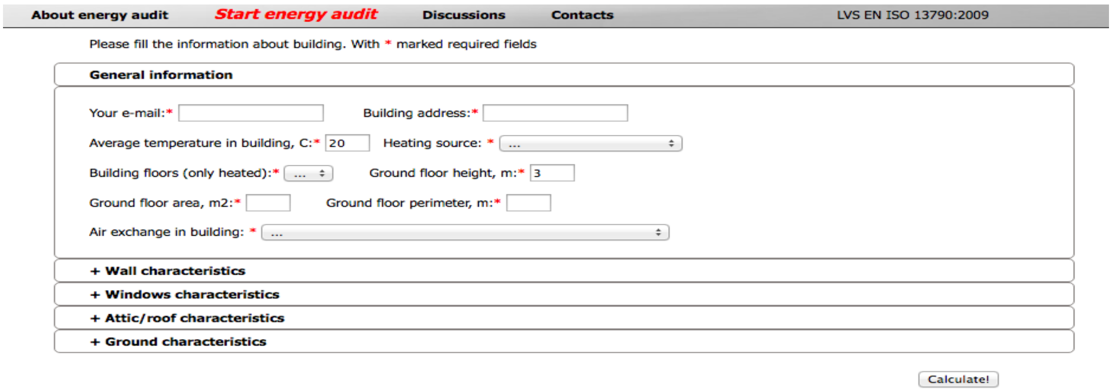

Figure 2.1 Energoaudits.eu data sheet

The ground floor layers can be formed of concrete, reinforced concrete, Rockwool, polystyrene insulation, wood, Granit and air.Once these data are inserted in the program, after choosing the building envelope material of each layer, and the window type, and the ground floor material of each layer, for example , the result sheet give the class of energy efficiency of the building as shown in figure 2.2.

Specific energy demand for heating area 96m2 is 480 (kWh/m2 year)

Building total heat consumption is 46.1 MWh/year, and total costs for year is 2883 euro/year.

Heat loss	MWh/year	Euro/year
Through walls	24.6	1535
Through roof	6.1	380.9
Through ground	7.4	462.1
Through windows	2.1	131.5
With air exchange (ventilation)	6	373.3
TOTAL	**46.1**	**2882.9**

Figure 2.2 Energy efficiency classification

Also the total heat consumption in MWh per year and the total cost per year, are displayed in the sheet of results. In accordance to construction standard a scale of the conductance kWh/m^2 of each part of the building envelope, the wall, the roof and the ground floor in and according to the values on a scale of five step starting from very good, good, moderate, bad, and very bad. (Figure 2.3).

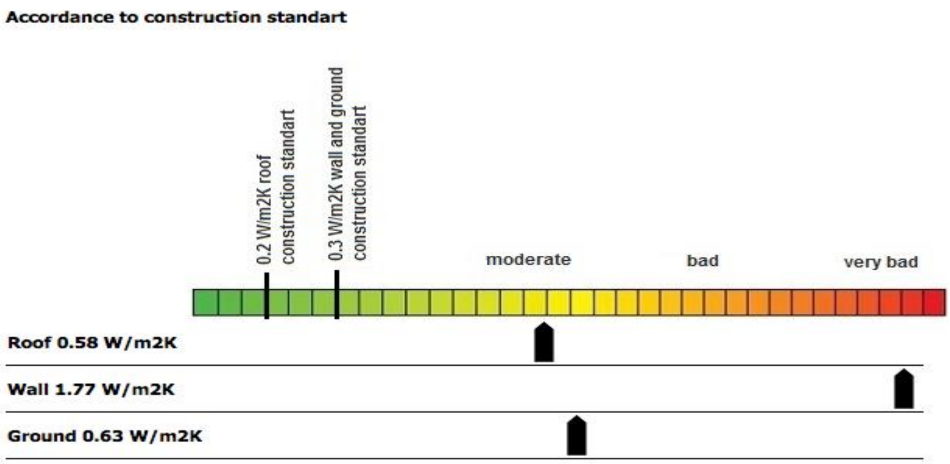

Figure 2.3 Building envelope efficiency scale

The second point is the technical economic calculation for energy efficiency actions. In this part, the measure to improve energy efficiency is to improve the wall insulation, the attic insulation, the ground insulation, the boiler change, and the type of new windows, by adding more thickness of insulation, and changing the type of windows and the results shown on the data sheet give the new energy efficiency class is shown in figure 2.4.

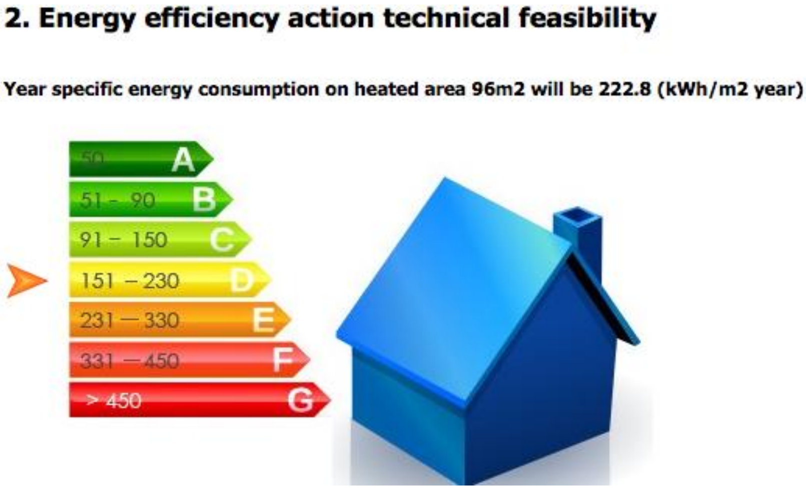

Figure 2.4 Energy efficiency action technical feasibility

The economical feasibility of the energy efficiency actions represented by the payback time, and different energy efficiency cost are displayed in Table 2.1. For the test example, the total cost of energy efficiency action of a conventional house of 95 m^2 is 13384 euros, and all energy efficiency actions will pay back in 9.5 years. Different energy action costs and payback time are shown in table 2.1.

Table 2.1 Different energy action costs and payback

Energy efficiency actions	Costs, euro	Payback time, years
Wall insulation	4284	4.1
Attic insulation	3600	24.7
Ground insulation	3600	15.9

Windows replacement	900	21.9
Boiler replacement	1000	
TOTAL	13384	9.5

2.2Simulation software programs

In this sub-chapter we attempt to analyze some of the features of the whole building energy simulation most used programs, eQUEST and EnergyPlus,using data from previous researchers, detailed features of the eQUEST can be found on DOE web site, and about EnergyPlus in reference[**34**]. The whole building energy simulation programs are more and more employed in the first step in the design process to help architects and engineers to take the best decision, and to choose which design alternatives are more energy efficient and cost effective. The United States department of energy developed both programs studied. Earlier they launched DOE program, the most popular program used for whole energy building simulation. The program DOE 2.1e uses as interface EnergyPro or visual DOE. The second version of DOE 2.2 engine uses Autodesk GBS5 (ecoTect), and eQUEST. Meanwhile EnergyPlus uses the interfaces, AECOsim energy simulator of Bentely Hevacomp[**35**], Design Builder and open studio. A comparison of the simulation results given by eQUEST and EnergyPlus, for annual energy consumption, using previous research work is done. Using some utility data from literature, to check the closeness of the simulation program with a real heat and energy flows in building, this theoretical study confirmed the previous researchers conclusions that eQUEST is the most easy program to use and the quickest in producing results that help architects and engineers to choose the most energy efficient design during the preparation phase.

With the increasing cost of energy in general, and in building in particular, this led to an increased interest in energy efficient building design.

Designing sustainable buildings that also fulfil all operational requirements of the users is an unprecedented challenge of our times. Researchers, practitioners and other stakeholders are faced with enormous challenges due to the need to recognize and take account of various dynamic processes around us, such as: global climate change, depletion of fossil fuel stocks, increasing flexibility of organizations, growing occupant needs and comfort expectation; increasing awareness of the relation between indoor environment and the health and well-being of the occupants, and consequently their productivity.

Whole building energy simulation tools are increasingly used for analysis of energy performance of buildings and thermal comfort of their occupants. Nowadays, there are many building simulation programs with different user interfaces and different simulation engines that are capable of these analyses. Because of the very wide and significant variety of these simulation tools, it is more important to understand the limitations of the tools and the complexity of simulations.

The reliability of data exchange and straightforward user- friendly interfaces are major aspects of the practical usage of these tools. Due to the huge amount of data that is to be input and the availability of rich 3D geometry rendering engines, effective data exchange and software interfaces are crucial to enable faster and reliable performance of the simulation tools [**36**]. Such systems can be classified as heterogeneous systems because they involve multiple domains, such as thermodynamics, fluid dynamics, heat and mass transfer, electrical systems, control system and communication systems [**37**]

The eQUEST software is one of the most popular programs used by the building simulation community. Simulation can be performed within few minutes using a computer. A DOE-2 energy model takes less than a minute or two in case of a tertiary building to complete an annual simulation run. eQUEST efficiency results from its hour-by-hour calculations, and the sequential structure of LOADS-SYSTEMS-PLANT-ECONOMICS which does not solve the thermal dynamics of building envelope with the HVAC system operating performance simultaneously.[**38**]

EnergyPlus is a new generation simulation program built upon the best features of DOE- 2 and BLAST, and adds new modeling features beyond the two programs. With DOE-2's limitations in modeling emerging technologies, more modelers, especially in academia and research community, have begun using EnergyPlus for their simulation needs. EnergyPlus does sub-hourly calculations and integrates the load and system dynamic performance into the whole building energy balance calculations which can provide more accurate simulation results but runs much slower compared with DOE-2 [**39**].The difference between the simulated results using EnergyPlus and the real values for annual gas consumptionshows a very large percentage of difference than when using eQUEST program [**40**].

Both the programs offer their own set of advantages and disadvantages. Other programs can be more or less close to one or another of these two major software, eQUEST and EnergyPlus. The purpose of this study is to perform a theoretical analysis of some of these programs by using previous researcher's works in the building energy simulation comparison field [**41**].

2.3 Literature background

Statistical results from previous researcher's works have been used in this building energy consumption analysis. Both electrical and gas real consumption were compared to the results of simulation by both eQUEST and EnergyPlus. The core tools in the building energy field are the whole-building energy simulation programs that provide users with key building performance indicators such as energy use and demand, temperature, humidity, and costs. Drury B etal., listed, a number of comparative surveys of energy programs, which have been published.

In his work, Drury hoped to elaborate a platform, which will become a living document that will evolve over time and will reflect the evolution of tools and evolution of language the community uses to discuss the facilities within tools.

This report first provides a brief overview of each of the programs. This is followed by 14 tables which compare the capabilities for each of the twenty simulation programs in the following areas: General Modeling Features, Zone Loads, Building Envelope and Daylighting, Infiltration, Ventilation and Multizone Airflow, Renewable Energy Systems, Electrical Systems and Equipment, HVAC Systems, HVAC Equipment, Environmental Emissions, Economic Evaluation, Climate Data Availability, Results Reporting, Validation, and User Interface, Links to Other Programs, and Availability.

In their report, Crawley et all [**38**] provided an up-to-date comparison of the features and capabilities of twenty major building energy simulation programs: BLAST, BSim, DeST, DOE- 2.1E, ECOTECT, Ener-Win, Energy Express, Energy-10, EnergyPlus, eQUEST, ESP-r, IDA ICE, IES <VE>, HAP, HEED, PowerDomus, SUNREL, Tas, TRACE and TRNSYS. They used the information provided by the program developers in the following categories: general modeling features; zone loads; building envelope, daylighting and solar; infiltration, ventilation and multizone airflow; renewable energy systems; electrical systems and equipment; HVAC systems; HVAC equipment; environmental emissions; economic evaluation; climate data availability; results reporting; validation; and user interfaces, links to other programs, and availability. After giving a brief overview on each of the twentieth simulation program investigated on the basis of the information published in the software developer's site, then, they started comparison among the different tools. The remainder of this report contains the 14 tables, which compare the capabilities and features of the 20 programs, which are listed alphabetically.

Table 1, general modelling features, table 2, zone loads, table 3, Building Envelope and Day-lighting, table 4, Infiltration, Ventilation and multi-zone Airflow, table 5, Renewable Energy Systems, table 6, Electrical Systems and Equipment, table 7, HVAC Systems, table 8, HVAC Equipment, table 9, Environmental Emissions,table 10, Economic Evaluation,table 11, Climate Data Availability, table 12, Results Reporting,table 13, Validation,table 14, User Interface, Links to Other Programs, and Availability.

Then, the authors arrived to these conclusions: first, there was not quite a common language to describe what the tools could do. There was much ambiguity, which will continue to require additional work to resolve in the future. Second: that there are many nuances of 'capability' that the developers found difficult to communicate. The authors attempt to clarify this by providing more depth than a simple X (has capability) by including P (partially implemented), O (optional), R (research use), E (expert use), or I (difficult to obtain input data) or through extensive explanatory footnotes. Third: they found that there was a relatively new level of attention and interest in publishing validation results. Fourth: there is also the issue of trust: Do the tools really perform the capabilities indicated? What level of effort and knowledge is required by the user? How detailed is the model behind a tick in the table? For open source tools, everyone can check the model and adapt it. For the other tools, only very detailed BESTEST-like procedures can give the answer. We may need a way for users to provide feedback and ratings for these in the future. And fifth, they suggested that this report should be used and developed as a community resource, which will be regularly updated.

The major second work is the master thesis of Hema Sree Rallapalli [**36**], which dealt with the comparison of the famous two EnergyPlus and eQUEST whole building energy simulation. In his work the author investigated the potential of both programs to do the whole building energy analysis and compare the results with the actual building energy performance. For this purpose the energy simulation of a fully functional building is done in eQUEST and EnergyPlus and the results were compared with utility data of the building to identify the degree of closeness with which simulation results match with the actual heat and energy flows in building.

The author observed in this study that eQUEST is easy to use and quick in producing results that would especially help in the taking critical decisions during the design phase. On the other hand EnergyPlus aids in modelling complex systems, producing more accurate results, but consumes more time. The choice of simulation program might change depending on the usability and applicability of the program to our need in different phases of a building's lifecycle. Therefore, it makes sense if a common front end is designed for both these simulation programs thereby allowing the user to select either the DOE-2.2 engine or the EnergyPlus engine based upon the need in each particular case.

The author concluded that the user interfaces for DOE-2 are currently more developed in comparison to the interfaces for EnergyPlus. The lack of user-friendly, mature and comprehensive user interfaces limits the usage of building energy performance simulation in practice. Current progress on interfaces to EnergyPlus is promising and is likely to provide adequate user friendliness and functionality in the future. They also suggested that the energy simulation tools itself need more development and research to improve the value and accuracy of energy simulation. An additional research and development of these tools could also, provide more accurate absolute values and provide many additional benefits to their users. They observed in their study that eQUEST is more easy to use and it is quick in producing results that would help in the decision make process during the design phase. On the other hand EnergyPlus can perform more complex modeling systems, but is more time consuming.

A third work was done by JoanaSousa [**42**], entitled “Energy Simulation Software for Buildings: Review and Comparison”. In this work the author set as objective to identify some of the most important energy simulation software due to their capacity of calculating a significant number of variables and to compare them in order to establish their differences. After giving a brief description of five energy simulation programs, EnergPlus, ESP-r (energy simulation software tool), IDA-ICE, IES VE (Integrated environmental solution, virtual environment), and finally TRNSYS, the author concluded that among the most complete simulation software tools are the EnergyPlus, the ESP-r (Energy Simulation Software tool), the IDA ICE (Indoor Climate Energy), IES-VE (Integrated Environmental Solutions - Virtual Environment) and TRNSYS being the most complete software tools, these are also the most complex and therefore require greater expertise.

From the analysed energy simulation software tools, TRNSYS is the most complete, but depending on the user perspective and final purpose the other software tools could be more appropriate. The major limitation of TRNSYS is to not being able to connect with AutoCad Software tool for importation and exportation of files. In this aspect Energy Plus, ESP-r and IDA ICE are more appropriate.

2.4 Results

All previous works concluded that even among the ‘mature’ tools, there was not quite a common language to describe what the tools could do. There was much ambiguity, which will continue to require additional work to resolve in the future. These tools do not follow the same pattern to deal with one side of the simulation of the building.

For the general modelling features, the simulation with BLAST, DOE2.1E, TRACE, have a sequential loads, and system plant calculation without feedback.For simultaneous loads, system and plant solution, almost all the programs perform the simulation except DOE2.1E, ECOTECT, and TRACE. For iterative non-linear systems solution, only the programs BLAST, DeST, DOE2.1E, Ener-Win, Energy express, eQUEST, and SUNREL do not perform the iterative non-linear systems solution. Softwares, BLAST, DeST, DOE2.1E, ECOTECT, Ener-Win, HAP, Tas, and TRACE, do not offer coupled loads, systems, plant calculations. The DOE2.1E, the eQUEST, they do not simulate space temperature based on loads-systems feedback. All the programs simulate floating room temperatures.

For the time step approach, the user selected for zone/environment interaction, nearly 50% of the software did not offer this opportunity. For variable time intervals for zone air/HVAC system interaction, only, BLAST, BSim, Energy Express, Energy plus, eQUEST , and ESP-r, offer air/HVAC system interaction. User selected for both building and systems, only ESP-r, IDA ICE, IES VE, PowerDomus, and TRNSYS, which offer this opportunity. The EnergyPlus, ESP-r, IDE ICE, offer dynamically varying based on solution transients; all the others do not offer this possibility while, all the softwares offer the full geometric description, walls, roofs, floors, windows, skylights, doors, and external shadings.

A detailed comparison between office building measured energy consumption (both for gas and electricity) and the result given by simulation using EnergyPlus, and eQUEST, are discussed. Table 2.2 gives a comparison between the measured and the simulated electricity consumption using the eQUEST program.

Table 2.2 Comparison of measured and simulated electric consumption in kWh using eQUEST

Month	Measured	Simulated	Difference	%
January	20136	22436	2300	0.95
February	19397	20641	1244	6.41
March	21291	23926	2635	12.38
April	23734	24270	536	2.26
May	28780	27686	-1094	-3.80
June	33516	32641	-875	-2.61
July	39480	39889	409	1.04
August	36877	35857	-1020	-2.77
Sep.	30989	29336	-1653	-5.33
October	24464	24232	-232	-0.95
Nov.	21118	22417	1299	6.15
Dec.	20489	20873	384	1.87

Table 2.3 Comparison of measured and simulated electric consumption in kWh using EnergyPlus

Month	Measured	Simulated	Difference	%
January	20136	23777.34	3641.34	18.08
February	19397	21091.93	1694.93	8.74
March	21291	23644.45	2353.45	11.05
April	23734	25665.67	1931.67	8.14
May	28780	29476.21	696.21	2.42
June	33516	30057.25	-3458.75	-10.32
July	39480	33704.96	-5775.04	-14.63
August	36877	30683.08	-6193.92	-16.80

Sep.	30989	28522.46	-2466.54	-7.96
October	24464	26763.62	2299.62	9.40
Nov.	21118	22818.53	1700.53	8.05
Dec.	20489	2178159	1292.59	6.31

The comparison of the simulated gas energy consumption using eQUEST program, and the measured data in the same office building is shown in Table 2.4.

Table 2.4 Comparison of measured and simulated gas consumption in kWh using eQUEST.

Month	Measured	Simulated	Difference	%
January	15675,5	16988,14	-1312,64	-8,37
February	17697,2	15483,585	2213,615	12,51
March	13214,3	14998,084	-1783,784	-13,5
April	9639,7	10006,243	-366,543	-3,8
May	9053,7	8935,914	117,786	1,3
June	8936,5	8285,454	651,046	7,29
July	7325	8596,327	-1271,327	-17,36
August	7705,9	8971,367	-1265,467	-16,42
September	8497	9056,63	-559,63	-6,59
October	11749,3	10403,551	1345,749	11,45
November	14855,1	15844,854	-989,754	-6,66
December	20334,2	17768,106	2566,094	12,62

The comparison of the simulated gas energy consumption using EnrgyPlus program and the measured data in the same office building is shown in Table 2.5.

Table 2.5 Comparison of measured and simulated gas consumption in kWh using EnergyPlus.

Month	Measured	Simulated	Difference	%
January	535	269,97	265,03	50,46
February	604	227,79	376,21	37,71
March	451	220,45	230,55	48,88
April	329	121,28	207,72	36,86
May	309	60,86	248,14	19,70
June	305	21,18	283,82	6,94
July	250	8,75	241,25	3,50
August	263	21,26	241,74	8,08
September	290	41,03	248,97	14,15
October	401	108,62	292,38	27,09
November	507	217,9	289,1	42,98
December	694	367,67	326,33	52,98

Results of comparison of two major whole building simulation programs show that when we are dealing with annual energy consumption, eQUEST results are much closer than results given by EnergyPlus results. The difference between the measured annual electrical energy consumption, and the simulated one using eQUEST program, are +/- 0.95% for January and October, the highest difference percentage registered is 12.38% for the month of March. The others oscillate between +/- 6%, and +/- 1%. Whereas, the same results, but when using EnergyPlus program, show a difference of 18% and 8%. Table 5 shows the detailed difference percentage between eQUEST and EnergyPlus, and it shows clearly that results obtained using eQUEST are closer than when using EnergyPlus. Table 2.6 shows the detailed difference percentage between eQUEST and EnergyPlus.

Table 2.6 Difference percentage between eQUEST and EnergyPlus

	Electricity consumption		Gas consumption	
Month	eQUEST%	E.P. %	eQUEST%	E.P. %
January	0.95	18.08	-8.37	4.13
February.	6.41	8.74	12.51	62.29
March	12.38	11.05	-13.50	51.12
April	2.26	8.14	-3.80	63.14
May	-3.80	2.42	1.30	80.30
June	-2.61	-10.32	7.29	93.06
July	1,04	-14.63	-17.36	96.50
August	-2.77	-16.8	-16.42	91.92
September.	-5.33	-7.96	-6.59	85.85
October	-0.95	9.4	11.45	72.91
November.	6.15	8.05	-6.66	57.02
December.	1.87	6.31	12.62	47.02

The difference between the simulated results using EnergyPlus and the real values for annual gas consumptionshows a very large percentage of difference compared to the results given by eQUEST program.

2.5 Conclusion

Although the program called energoaudits.eu is very easy for every one to use, without the need to be an architect or an engineer, all you have to do is to characterise the building. Build on the input the program calculates building energy efficiency class (A,B,C,D,E), heat losses, heat costs, building accordance to construction standard, etc.

This program is just an approximation and the modelling of the potential energy efficiency actions from technical-economical point of view.

This program does not take in consideration the following:

1. the weather data, which is very important in determining and calculating the heat load and cooling load, is not taken into consideration.
2. The full geometric description, the shape of the building, while all other softwares offer the description of walls, roofs, floors, windows, and so on.

3. In heating sources, heating coil, district heating, and gas fired boiler or electric boiler are not mentioned.
4. Building material library in this program is very limited and mixed by thermal insulation material compared to the library of eQUEST and EnergyPlus.
5. For glass windows only three types are cited in the program, single glass, old double window, double plastic window, and triple glass window, the glass category is not mentioned at all like low emissivity glass, colour, selectivity, air filling between double or triple glass, and it has direct effect on heat flow through the glass.
6. The orientation of windows and doors are not fitted in this program.
7. Attic/roof characteristics such as ventilated, not ventilated, is not among the library of this program, also the material library is very limited.
8. Ground floor characteristics in the program give only two choices, above the ground and on the ground, but no mention of walls below the ground.

For the general modelling features, the simulation of the BLAST, DOE2.1E, TRACE, have a sequential loads, system, plant calculation without feedback, for simultaneous loads, system and plant solution almost all the programs perform the simulation except DOE2.1E, ECOTECT, and TRACE. For iterative non-linear systems solution, only the programs BLAST, DeST, DOE2.1E, Ener-Win, Energy express, eQUEST, and SUNREL do not perform the iterative non-linear systems solution. Softwares, BLAST, DeST, DOE2.1E, ECOTECT, Ener-Win, HAP, Tas, and TRACE, do not offer coupled loads, systems, plant calculations. The DOE2.1E, the eQUEST, they do not simulate space temperature based on loads-systems feedback. All programs simulate floating room temperatures.

For the time step approach, the user selected for zone/environment interaction, nearly 50% of the software doesn't give this opportunity. For variable time intervals for zone air/HVAC system interaction, only, BLAST, BSim, Energy Express, Energy plus, eQUEST , and ESP-r, offer air/HVAC system interaction. User selected for both building and systems, only ESP-r, IDA ICE, IES VE, PowerDomus, and TRNSYS, which offer this opportunity. The EnergyPlus, ESP-r, IDE ICE, offer dynamically varying based on solution transients; all the others do not offer this possibility, while, all the softwares offer the full geometric description, walls, roofs, floors, windows, skylights, doors, and external shadings.

In our case, we are interested in the residential energy consumption for heating season, and the results of the comparison of different softwares. When dealing with annual energy consumption, eQUEST results are much closer than the EnergyPlus results.

ANALYSIS OF ENERGY CONSUMPTION IN RESIDENTIAL BUILDINGS IN ALGERIA

3.1. Introduction

Access to electricity and gas, main energy sources used in urban areas, is a major issue of social and economic development in Algeria. The total installed capacity of 11,325 MW in 2010 covers 98% of the electricity energy demand. Remote sites (off-grid) in the south, which account for 86% of the country land and 7% of the population, are generally supplied with electricity by generators running on diesel.

According to the national electricity and gas authority, the Société Nationale d'électricité et de Gaz[**43**] All the northern and southern cities have access to electricity, meanwhile, some rural area in the southern part still provided by generators working on diesel, Agglomerations who have electricity represent 98% of the population, 45.79% of the population have access to natural gas network.

Renewable energy represents a very small part in the national energy balance, i.e. 0.02% of national electricity consumption despite the huge solar resources in the MENA countries (Middle East and North Africa). According to Treib (Franz Trieb et al., 2012), concentrated solar power (CSP) plants would be able to supply 15% of electricity demand with less than 0.2% of the suitable land. This paper starts with a historical review of the evolution of electricity and gas from 1962 until 2005, followed by a detailed residential energy cost evolution. A literature review about previous comparative studies on household energy consumption is exposed, then, a total final energy consumption analysis by sectors and type of fuels is detailed. Total energy consumption in residential buildings is analyzed, and a summary of a survey on residential energy consumption in Setif area, Algeria, was discussed.

3.2 Evolution of the electricity and gas sectors in Algeria

The electrification of the country after the independence (1962) showed an extreme disparity between urban and rural areas, reflecting the geographic distribution of populations under colonization. During French occupation, for 450 villages and 1,000 farms,only 1600 km of (Medium voltage) MV and 1250 km of (Low voltage) LV were connected to the power grid [44],The national electricity production reached 1134GWh for an equivalent total installed capacity of 568 MW,The Algerian network is connected to Morocco and Tunisia grid. [45]

In the early seventies the sector experienced a significant growth reflecting the various development programs, which were launched. The expansion of the electric power grid between 1980 and 2010 is very important. Population growth with a rate of 3.2% per year during the period 1970-1990 was the determining factor for the acceleration of the electrification of the country.The nationalelectrification jumped from 53% in 1975 to 80% in 1985. The power grid has evolved to cope with the growing number of subscribers.

The annual population growth for midyear population between 2007 and 2010 is 1.5%. The number of electricity subscribers was 720000 in 1970, with only a percentage of 41%, with a population of 15.5 millions. In 2010, the number of subscribers reached 6.8 millions, with a covering percentage of 98%.

The development in rural housing during the post independence years has been the one thousand Socialist Villages program undertaken in 1972 in conjunction with the agrarian revolution program. Socialist villages represented a pilot plan for improving rural housing. According to the plan, each village would have a population of as many as 1,500 people housed in 200 individual units, together with schools and clinics. Each unit was to have three rooms and would be provided with electricity, heat, and running water. Although the villages had much to commend them, the program has done little to slow migration to urban areas.

Between 1990 and August 1993, as part of a series of reforms, the government has sought to eliminate the housing backlog and has built about 360,000 public housing units and launched new housing programs for low-income groups. Earlier plans to produce 100,000 public housing units between 1980 and 1984 achieved only a 57% rate of success.These programs were, together with the development of industry, accompanied by a significant growth of population, this population must be connected to electricity grid and water services. The electricity consumption in 1962 (the year of the independence), was 993 GWh.It reached 35800 GWh by the end of 2010. The number of dwellings is nearly seven millions.

Rural migrants settled into bidonvilles, named after the flattened bidons (tin cans) used extensively in their ramshackle construction. After independence the bidonville population of Algiers alone soon exceeded 100,000. Bidonvilles are connected to the electricity but are difficult to estimate their numbers exactly. The mean target of the government is to eradicate this bedonvilles by construction of social very low rent flats through all the concerned cities, program that have a success, because some bidonvilles have been completely disappeared[46].

The total number of houses connected to electricity grid was 6.8 million houses in 2010, and are distributed as follows:

1. Less than 20 000 subscribers in the south west –Tindouf- next to the border of the southern sahara, and south east –Illizi- next to the lybian border.
2. Between 20 000 and 100 000 subscribers, are distributed all over the country, including the following provinces –El Taref , –Biskra-Tiaret-Ain timouchent-Saida-Laguat-Ghardaia-Adrar-Bechar-El Bayad-Neaama-Tamanghasset.

3. Between 100 000-200 000, The following provinces: Ouragla, El Oued, Djelfa, Media, Chef, Relizane, Mostaganem, Sidi Belabs,Annaba, Skikda, Souk Ahras, Oum Elbouaghi.
4. More than 200 000, The following provinces: Batna, Setif, Bordj Bou Arreridj, Bejaia, Tizi ouzou, Alger, Oran, Tlemsen, Boumerdes.

This difference of the distribution is mainly due to the concentration of population in these areas, in the southern part, the concentration of the population is very low, compared to the northern part or the highlands.

For gas penetration distribution, in the last decade, the localities connected to the natural gas reached 1369, raising the rate of natural gas penetration from 30.8% to 45.7%, and it is expected to reach 47.7% by the end of 2011, 49.5% by the end of 2012, 51.1% by the end of 2013, and 52.6% by the end of 2014.

Almost 71 locations are connected annually to natural gas during the last ten years against only 6 locations per year between 1962 and 2000. Transported gas bottles currently supply the rest of Algerian territory.

The gas transport network has a total length of 10800 km; the distribution network is almost 36900 km. The evolution of low-pressure gas customers in millions is represented in Table 3(Newsletter press number14, 2011Sonelgaz).

Four propane stations feed 1.7 million houses, 800 m3 station to feed Tindouf; 700 m3 for Janet, two Liquefied propane gas are expected to be commissioned in late 2012.

It should be noted that only three propane stations were operational in 2000; each with 300 m3 covering the province of Collo , Kala, and Elbayad, By the end of 2010, five other propane stations start serving; El Ménéa with 300 m3, Bechar with 1200 m3, Guerrara with 500 m3, and el Oued with 800 m3.

The total length of gas distribution network jumped from 16543Km in 2000 to 52403 km in 2010, which represents an increase of 217%. The Northern provinces have been connected before 2000. In 2010 all the highlands and most of the northern part of Sahara has been connected to the gas network, by the end of 2012, the northern part of Ourgla, Ghardaia, el Bayed, Naama are expected to be connected.

Tamanghasset, south Adrar, Tindouf, Bechar, South el Bayad south Ghardaia, south Ouragla and Illizi still not covered by the natural gas network.

Tamanghasset, south Adrar, Tindouf, Bechar, South el Bayad south Ghardaia, south Ouragla and Illizi still not covered by the natural gas network.

Renewable energy programs also provide connection to electricity using solar energy for remote areas, which justify the implementation of isolated networks. The PV solar program within the scope of the rural electrification program is of the order of 5 MW.

Solar energy is powering 18 remote villages, 5 villages at Illizi, 8 at Tamanrasset, 2 at Adrar, and 3 at Tindouf. 16 other villages to be powered by solar energy, 2 vilages in Illizi, and one in each of the following provinces, Tamanrasset,El Oued, Ghardaia,El Bayad, Naama, Tlemcen, SBA, Saida, Tissemsily, Djelfa, Msila, Batna, Khanchela, and Tebbessa.

3.3 Algerian residential energy price policy

The electricity and gas bill for residential consumption is divided into two slices, the evolution of the price of the first slice jumped for 1 kWh, from simple to nearly double, (from 0.935 DA in June 95 to 1.779 DA in April 2006,) for the second slice it jumped from 1.609 to 4.179 DA, which is more than 2.5 times.

However, for natural gas with which most cities are fed, the unit price has risen from 0.149 DA/unit for the first slice to 0.168 DA/unit. Consumption up to 1125 units was considered first slice was until June 2006, when the utility company decided to reduce it from 1125units to 375 units, which means that the price of the first slide has not only risen from 0.149 to 0.324DA/unit, but also the number of unit consumed for the first slide which was 1125 has been reduced to 375units, making 750 units switched from first slice to second slice with a unit price of 0.324 DA/unit, which results in more than tripling the cost. The unit price of the second slice (>1125) jumped from 0.295DA/Therm to 0.324 DA/Therm in just few months from June 2005 to April 2006, taxes followed nearly the same increase.

3.4 Residential energy invoice calculation

The energy consumption invoice is issued every three months for both electric and natural gas, in which appear different in formations such as the reference number, the current account number of the local utility company which is itself a sub-company of Sonelgaz , the name of end user, its address and the consumption index for both gas and electricity. It shows the difference between the previous and the new meter index. This difference is multiplied by a coefficient equal to 1 for electricity consumption and 8.7 for natural gas consumption for Setif area.

For electricity domestic, customers are charged 1.779 AD (0.02239 USD)/kWh for the first 125 kWh consumed, excluding taxes, the remaining consumption is charged 4.179 AD (0.05259 USD) per kWh. For natural gas, the customer is charged 0.168 AD (0.00211 USD) per Therm.Since May 2005, the price of the energy was fixed by government decision published in the official journal of the Algerian republic. The first 125 kWh of electric energy consumed are charged at 1.779 AD (0.02239 USD) without taxes, the remaining are charged at 4.179 AD (0.05259 USD) kilowatt-hours without residential consumption taxes. Non-residential consumption is charged 4.179 DA per kilowatt-hour without taxes.

The unit price of natural gas and electricity consumption was fixed according to the decision D/06-05/CD of May 30th, 2005. The difference between new and former meter index is multiplied by a coefficient, which is a function of temperature and altitude, and which is equal to 8.7 for Sétif area. The first 375 units are charged 0.168 DA(0.00211 USD)/Therm, the rest at 0.324 DA(0.00408 USD)/ Therm. Taxes for electricity consumption are charged on the basis of the amount of the energy consumed, those who consume less than 70 kWh, are exempted from the taxes E50 called fixed rights, consumption between 71 and 190 kWh is charged 25 DA (0.31459 USD), from 191 to 390 is charged 50 DA (0.62917 USD), consumption over 391 kWh is charged 100DA (1.25834 USD). Taxes called M99 are set by the finance act (Law 05-16 of December the 31, 2005) and depend on the amount of the invoice, void if the amount is less than 50DA (0.62917 USD), 0.5DA (0.00629 USD) if the amount is between 50DA (0.62917 USD) and 500DA (6.29171 USD), for more than 500 DA, each 100 DA (1.25834 USD) is charged 1 DA (0.01258 USD) with a maximum of 2500DA (31.4586 USD). VAT is fixed at 7% for consumption and 17% for delivery.

3.5The public energy program

The growth of electricity consumption in Algeria shown in Table 8, reached its highest level in the seventies, with an average annual growth rate of 13% recorded between 1970 and 1980.Over the past decade, this growth was practically stable around an average annual rate of 5.6% (3.7% between 2008 and 2009). Thus, the maximum power demand (MPD) in July 2009 was two times higher than that recorded in summer 2003. This growth is expected to continue in the future, driven by the increasing use of air conditioners (with constant industrial activity, the MPD in July 2009 reached a difference of more than 2000 MWh compared to April 2009, 35 % difference). SONELGAZ provides for an average annual growth rate of customers of 4.24% over the period 2010-2020.It is expected to reach 10 million customers by 2020 [43]

The overall energy consumption share is 12% for electricity, 29% for natural gas, 11% Liquefied propane gas, and finally 48% for petroleum products.

The realization of public programs for gas distribution and rural electrification over the period 2010 - 2014 is planning to feed more than one million homes with natural gas and connecting more than 220,000 isolated homes with electricity.

To set this program, the realization of almost 6000 km of gas transmission networks, and more than 32 000 km of gas distribution networks to serve about 1,840 localities in natural gas is expected, and to power 220,000 isolated homes with electricity,the realization of more than 21 000 km of medium and low voltage networks is also planned.

Algerian program consists as well in installing a power from renewable sources by almost 22,000 MW between 2011 and 2030 in which 10,000 MW will be dedicated to export.One of the main objectives is to raise the share of renewable energy for national consumption up to 40% by the year 2030.It is expected to realize solar power plants with a total capacity of 800 MW between year 2013 and 2020, and with total capacity of 2000 MW between years 2021 and 2030. The program provides the realization of solar thermal power plants with a total capacity of 1475 MW between 2013 and 2020 with a total capacity of 5700 MW between 2021 and 2030.

The realization of wind turbines farms with a total capacity of 270 MW between 2013 and 2020 with a total capacity of 1730 MW between 2021 and 2030 is intended as well.

Energy consumption evolution is indicated as provided by SONELGAZ. The national utility company SONELGAZ had at the end of 2009 nearly 6.5 million customers with electricity.

3.6 Methods

Previous comparative studies on household energy consumption have shown the impact over time on gas consumption of market factors such as a growing customer base, varying mix of dwelling types, changing share of vacant dwellings, changing size of new dwellings [47] using different parameters, such as income and relative standard of living [48], and electrical energy price [49].

In his paper, [50], carried out an analysis of energy consumption and carbon dioxide emissions from 17 countries of the Middle East and North Africa, using Data Envelopment Analysis. He did not give any information about the sectors and type of fuel consumption. [51]And([52]in their studies, they investigated the relationship between energy consumption and economic growth – causality analysis- of some African countries for the first writer, and for Algeria for the second writer.[53], studied the relationship between energy consumption price and economic growth for the sub-saharien African countries, the same thing could be said for the many other authors.

Up to my knowledge, none of the previous investigations have analyzed the energy consumption by sector and by a type of fuel in Algeria, or studied the residential energy consumption.

Mywork tries to bring some light on this subject and to fill this gap if possible. Some publications from different services of the ministry of energy and mine give information on the national energy balance for each year. For the year 2010 the national energy balance, The total available energy, which is the sum of national production, imports and stocks reached 165 MTOE against 167 MTOE in 2009, with a decrease of -1.3%.

The export have a share of 74% of national production, the rest was used to cover national needs (26%). The share of residential and tertiary sector is 39.22% from final energy consumption, followed by transport with 35.43%, and finally by industry and building construction with a share of 25.33%. The final energy consumption by fuel is 1.11% for solid combustible, 38.77% for liquid combustible, 32.91% for gas and 27.19% for electricity.

Several studies were conducted through deferent countries such Wales in England[54], and in Netherlands [55] to investigate the influence of building regulations on energy consumption. Fayaz, R. and Kari [56] compared the energy conservation building codes of Iran, Turkey, Germany, and China. Saidur, R.,[57]analyses the energy consumption, energy saving, and emissions in Malaysian office building.

The Wei Pan study reveals that the compliance with the building regulations was poor at a level of 35%, accompanied by 43% grey compliance, and 21 grey non-compliance, due to the failure to present sufficient evidence of achieving required CO2 emissions reductions.

Olivia Guerra concluded that the lack of correlation between energy performance coefficient (EPC) and energy consumption for heating might be due to three factors:(1) the normalization factor per dwelling size might have a small effect on the correlation between the EPC and energy consumption; however this does not have an effect on the relationship between the expected and actual energy consumption; (2) the differences between the building characteristics as described in the EPC calculation and the actual building characteristics; and (3) the effect of occupants behavior on energy consumption. A lower EPC value is expected to reduce energy consumption because it increases the energy efficiency of buildings. The regulations have ensured that more energy-efficient dwellings were built after their introduction.

3.7. Total final energy consumption analysis by sectors and fuel type

The energy total final consumption (TFC) in 2007 reached 20 millionTOEfor a 34.4 millioninhabitants with 2 393367 square km, and with Gross Domestic Product (GDP) equal to 9389.70million DA (Algerian Dinars). The consumption per capita, in Algeria is 1,058.0 Kilograms of oil equivalent (kgOE) per person, while for Morocco, which nearly the same number of inhabitants is 458 (kgOE) and in Tunisia is 843 (kgOE) (earthtrends.wri.org 2012).The total gas emission is equal to 46 millions of tonnes of CO2 with an average of 3 TECO2/TOE. The GDP is equal to 3232.2 million of DA.

This is firstly due to fuel prices in Algeria, and probably due the level of average living standard and purchasing power, which is greater in Algeria than its neighboring countries. The % of population having access to electricity is, when writing this paper, and according to the World Bank, is 99.3 %for Algeria, 97% for Morocco, which counts nearly the same number of inhabitants [58]

Thus, allowing the access of Algerian citizens to more electrical appliances such as air conditioning units, and refrigeration, TVs and so on, and natural gas appliances such as gas boiler for central heating and hot water, gas stove, and gas cooker. The percentage of population connected to electric power is 99.5%, in Tunisia, butconsumption of natural gas in Megajoules per capitafor year 2006, is 17287 while it is 33353 for Algeria, and 776 for Morocco [59]

Total energy consumption distribution by fuel type shows that oil isthe most consumed fuel,shares are as follows:48% share for oil products, 29 % share for natural gas, 12% for electricity, and 11% for LPG, GDP per inhabitant is equal to 93959DA with an average consumption of 0.581 TOE per inhabitant. Meanwhile the final gas emission is 1.83 teCO2 and the primary emission is 2.222 TECO2 per inhabitant. Sector shares in Total energy consumption are 7% for agriculture and hydraulics, 33% for transportation, 19% for industry(withouthydrocarbons) and building construction, 41% for residential and tertiary sector. The final energy consumption by type of fuel and by activity sector is shown in Table 4. The percentage of CO2 emission in Algeria between 2009 and 2010 according to the global energy statistical Yearbook [50] is 4.2% of the global emissions, which is less than African emission percentage for the same period 5.8%.

The average annual growth rate in petroleum industry is 5.93%, and in gas industry is 4.84%,for this recorded rate, the average annual growth of agriculture and water resources, industry-building construction, residential - tertiary, and finally transport.

The percentage of the average growth in the residential and tertiary sector is merely the same as in petrol industry, the transport has an average less than in the petrol industry, Whereas, both industry - building construction, and agriculture –water resources illustrate a percentage value more than that of the petrol industry.

The total energy annual growth consumption counts for 27.67kTOE, therefore producing annual amount of 76.47 million TCO2.

For an average annual growth rate of 8.7% in the agriculture and water resourcessector,6.46% in industrialand construction sector,5.9% in residential and tertiary sector, and finally 5.76% in transportation sector, therecorded average annual growth rate in petroleum industrywas 5.93%, and 4.84% in gas industry.Energy industry sector consumption amounts to 5680.4 TOE and the consumption of non-energy industry sector is equal to 1994.24 TOE. The global consumptionis equal to 27665.6 TOE with CO2 emissionof 76446 653TECO2.

Consumption trends analysis by sector, and product between years 2000 and 2007, shows that the national final energy consumption registered an annual average growth rate of about 6.32%. The final energy intensity in 2007 reached 6TOE/MDA, which means 0.411 per 1000 dollars of GDP and twice that in OECD countries. Thus, the economy consumes twice as much energy as required to create the same unit added value, with a primary energy intensity of 3.82TOE / MDA (or 0.27 Toe/1000$).

The evolution from 1971 to 2008 of world total final consumption by fuel (MTOE) has doubled, it was in 1973, 4676 MTOE and it reached 8428 MTOE in 2008 according to the (Key word energy statistics, international energy agency 2010).The fuel shares of total final consumption are 15.6% for gas, 41.6% for oil, 9.8%for coal/peat, 17.2% for electricity, 12.7 as combustible renewable and finally 3.1% for others.

Total energy consumption distribution by fuel type shows that the oil is the most combustible consumed, this is due to the growing industry demand and transport. The consumption of natural gas for industrial purposes, such as electricity production by thermal stations using natural gas, comes in second place because of the increasing demand in residential and tertiary, as well, as in energy-industry, and non-energy industry. The increasing demand for electricity represents 12%. Liquefied propane gas consumption is increasing and this due to the encouragement of the government for use of this clean fuel for transport vehicles in private cars, by exempting them from pollution taxes, as well as installing more centrals for cities not served by natural gas.

3.8. Total energy consumption analysis in residential buildings

The final energy consumption in residential buildings has achieved the value of 6.5 millionTOE, in 2010, for almost 4.4 million housing units in urban areas, and 1.9 million housing units in rural areas, with an average number of occupancy of 6 persons per house. The household electrical equipment consumption accounts for 75% of the total electrical energy consumed in the dwellings, the remaining 25% are for the light.The average annual energy consumption of housing unit is 1.048TOE.The natural gas consumed in residential buildings represents 66%, petroleum products 22%, and electricity 12%. The power consumption of the residential sector reached 770 kTOEwhich represents 33% of the total electricity consumption, and 436 kTOE in gas, whichrepresents 70% of total gaseous product.

3.9 Residential energy consumption survey in Sétif

During the period 2000-2010, students of architecture department, Setif university were asked as a part from their home work to carry out surveyon their own residences, and after being familiar with the calculation of the energy needs for the buildings, simultaneously with the calculations of heating and cooling load.Each student was asked to evaluate his own house energy loss or gain, and energy needed for both heating and cooling seasons, then checks the results with both the recommendation of the nationalthermal regulation, and the energy bills.They were as well asked to make suggestions on how to improve the insulation and to reduce heat loss in winter and heat gain in summer. The total numbers of houses investigated was 1050, houses and flats built before 1986 were excluded. 600 dwellings were chosen among these collected dataaccording to the type of houses and flats, attached and detached houses, and the different kind of flats.454 flats, which represent75% of the dwellings, and 146 houses representing 25%, are investigated, 116 attached houses, and 30 detached houses, this represents approximately the rate of type of dwellings at the national level. The surveyincludesdetailed information about houses, flats, heating systems, hot water systems, electrical appliances, and living standards. The energy reported from gas-heated dwellings included energy for space heating, water heating and cooking. Electricity is rarely used for cooking because it is very expensive compared to natural gas.

A-Houses

For the houses, each student should answer questions about the house site, the climatic zone of the city, or a village, and whether the house is attached or detached, and if it is shielded from wind by other buildings or trees or unshielded, if it is unshielded, how strong is the degree of the exposition to wind. They should answer questions about the type of building materials used for the construction of the external walls, stones, bricks, or pressed earth blocks, the number of external wall layers, the thickness of each layer, and type roofs with their number of layers, the materials used for doors and windows, wooden or metallic. In the questionnaires, they have been asked to provide information about the total external surfaces, the external windows and doors area surfaces, the air leakage through windows and doors, and the ventilation systems.

B-Flats

The flats were classified according to the number of external walls, A type flats, those in the corner and at the last floor have 3 external walls and one roof, B type flats, the same number of externals walls, but the horizontal surface is the floor. C flats have 3 horizontal external walls, but the ceiling is the floor of the upper level and the floor is the ceiling of the lower floor. D flats have 2 vertical external walls and a roof, and are situated in the last floor. Fflats are the same as flats type D but instead of the roof they have a ground floor. E flats have 2 external walls, the roof is the floor of the upper floor, and the floor is the ceiling of the down floor.

C-Heating systems

The heating systems for the houses investigated varies with the site and the social status of the owners, in rural area, some houses use just a stove fired by bottled butane gas, others use the diesel fired air heater. In villages and cities linked to natural gas net, natural gas air heater is the most used, but some others use the gas fired boilers central heating systems and hot water. Villages not connected to natural gas use oil fired air heater, or boilers for central heating systems.

D-Domestic Hot Water

Either a 5 or 10 liters gas fired water heater produce the domestic hot water. When the house is equipped with a wall mounted unit boiler for central heating, usually the capacity of the installed boiler include the production of hot water, for 25 kW unit 10 kW is reserved for domestic hot water. If a floor boiler equips the house with capacity of 45 to 70 kW for central heating, a separate heat exchanger with different sizes provides the domestic hot water.

E-Living standards

The surveyed persons were asked to provide information about their living standards, the incomes of the householders, their salaries range, the numbers of the working people and who are participating in paying the energy charges among the occupants, and the number of occupants.

Heating and cooling loads were calculated using the Algerian regulation technique document DTR C3-4 entitled “Buildings heating and cooling load calculations manual” [61]. The heat loss calculations were done according to DTR [62] (thermal regulation in residential building, heat loss calculation). Wind exposure impact not cited in Algerian documents, has been taken into consideration according to method [63], and [64]

3.10 Setif climate characteristics

Algeria has six different climatic zones, Zone A (MediterraneanSea cost, littoral), zone B and B’ (high lands), zone C (north south); D and zone D’ (Sahara desert), and a sub-zone called B'. Each zone has three altitude levels, less than 500m, between 500 and 1000m, and over 1000m, excepted for zone B' which is less than 500m.[65]Detailed tables of the coldest and the hottest months can be seen in the previous reference[65]., together with the base dry bulb temperature, wet bulb temperature, and moisture contents.

Setif region(where the survey was done) is situated at latitude: 36° 11' 29 N, longitude: 5° 24' 34 E, altitude: 1080 meters. Its area covers three zones D, C, and B.There are two municipalities situated in zone Dto the south, twenty seven other municipalities in the midland, inzone Cand at the northin zone B the rest of the municipalities.The province of Setif has a central position with six thousand five hundred and fifty square kilometres (6550 km2) with a population of one million and six hundred thousand inhabitants (1.6 million people).It is limited by the provinces of Bejaia and Jijel in the north, by the province of Mila in the east, by the provinces of Batna and M'Sila in the south, and to the west by the province of Bordj Bou Arreridj.

3.11. Results and discussion

The number of dwellings studied is 600 houses, 454 flats, and 146 houses. The heat loss by transmission for an apartment or dwelling, according the Algerian thermal regulations, must be less or equal than 1.05 of a reference value of heat loss, which is calculated by the following:

$$D_t \leq 1.05\, D_{ref}\,[W/°C] \tag{3.1}$$

Where D_t is heat loss by thermal transmission of the apartment, and Dref is the reference heat loss. The reference heat loss is calculated by the following formula:

$$D_{ref} = aS_1 + bS_2 + cS_3 + dS_4 + eS_5 \left[\frac{W}{°C}\right] \tag{3.2}$$

Where S_1 in [m²], is the wall surface of the building envelope, which is in contact with outdoor air temperature. It could be a ventilated basement, attics, not heated volume, or soil. It includes roofs. S2 floors including floors over ventilated basement or not heated space, in our survey this value is equal to zero for flats type A, D, C, and E, S3 walls, S4 doors, S5 windows and window-doors, S1, S2, S3, dimensions are counted from the inside, S4, S5 are counted from the opening in the wall, a, b, c, d, and e are coefficient in [W/m²°C] and depend on type of dwellings and climatic zone as shown in table 3.1.

Table 3.1 coefficient values

Zone	Logement individuel					Logement en immeuble collectif				
	a	b	c	d	e	a	b	c	d	e
A	1,10	2,40	1,40	3,50	4,50	1,10	2,40	1,20	3,50	4,50
B	1,10	2,40	1,20	3,50	4,50	0,90	2,40	1,20	3,50	4,50
B'	1,10	2,40	1,20	3,50	4,50	0,90	2,40	1,20	3,50	4,50
C	1,10	2,40	1,20	3,50	4,50	0,85	2,40	1,20	3,50	4,50
D	2,40	3,40	1,40	3,50	4,50	2,40	3,40	1,40	3,50	4,50
D'	2,40	3,40	1,40	3,50	4,50	2,40	3,40	1,40	3,50	4,50

Most apartments in Greater Setif area are built with five layers external walls, starting from the inner side to the outer side, 1.5cm of plaster, 10cm ofred bricks, a10cm air gap and 10cm red brick layer and finally 1.5cm external cement mortar.

The average value of the overall heat transmission coefficient (conduction, convection and thermal radiation) or coefficient -a-, for external walls of houses, whether they are attached or detached, is equal to 1.87 W/m²°C in climatic zone A, 1.63 W/m2°Cfor climatic zone B, and 2.21 W/m²°C for climatic zone C.The average value of the calculated coefficient -coefficient b- (overall heat transfer coefficient)for house's floors is equal to 2.53 W/m^2°C for climatic zone A, 2.30 W/m^2°Cand 2.61 W/m^2°C respectively for climatic zones A, and B. The coefficients for internal walls (walls not in contact with outdoor air) have nearly of the same value, and are very close to the reference values.The value of coefficients for windows -d- varied with the type of window, the type of glazing, single or double, The frame metallic or wooden, the quality of joins. The mean value of this coefficient is equal to 4.5 W/m2°C for climatic zone A and 3.9 W/m^2°C and 4.7 W/m^2°C, respectively for zone B, and C. The mean value of the overall thermal coefficient for doors has been found to be the same when the doors are wooden and greater when the doors are metallic.

The overall heat transmission coefficient for the surveyed flats has been found to be the same as the building regulations reference value for all climatic zones for interior walls not in contact with outdoor air.It has been found to be the same for windows and door windows, but for doors, it is nearly the same for doors in climatic zone A, and different for climatic zones B and C, for the latter, the differences between reference value and calculated value are 0.15 W/m^2°C and 0.12 W/m^2°C.

For external walls, including roofs, the biggest difference appears in climatic zone C, with 0.37 W/m^2°C and the lowest in climatic zone A with 0.10 W/m^2°C, the difference for climatic zone B is 0.19W/m^2°C.

The overall heat transmission coefficient for floors is equal to zero for flats type A, C, D, and E, but for surveyed flats type B, it has been found 2.55 W/m^2°C, and 2.63 W/m^2°C for flats type F, the big difference between the average value and the reference value for floors coefficient appears in climatic zone A, with a value of 0.19 W/m^2°C, followed by zone C with a value of 0.18 W/m^2°C, and finally the zone B with 0.1 W/m^2°C.Detailed results for flats are gathered in the table 17(3.2)

Zone	Houses									
	a_{ref}	a_{cal}	b_{ref}	b_{cal}	c_{ref}	c_{cal}	d_{ref}	d_{cal}	e_{ref}	e_{cal}
A	**1.10**	**1.87**	**2.40**	**2.53**	**1.40**	**1.42**	**3.50**	**4.5**	**4.50**	**4.55**
B	**1.10**	**1.63**	**2.40**	**2.30**	**1.20**	**1.18**	**3.50**	**3.9**	**4.50**	**4.45**
C	**1.10**	**2.21**	**2.40**	**2.61**	**1.20**	**1.25**	**3.50**	**4.7**	**4.50**	**4.50**

For example for apartments type D, the results of the mean heat loss by vertical envelope surface including doors and windows is equal to 130.28W/m², the average heat loss by volume is equal to 11.63 W/m^3.

Thermal heat loss by air change for spaces excluded the basement and attics are calculated by the following formula:

$$d_r = 0.34NV \left[\frac{W}{°C}\right] \tag{3.3}$$

Where N is the air change by hour [1/h] and it is given by the regulation for different non-heatedspaces, V is the non-heated space volume in cubic meter. For detailed calculation the rule give the following formula:

$$d_r = 0.34(Q_v + Q_s)[W/°C] \tag{3.4}$$

Where Q_v is the specific ventilation volume in cubic meter by hour and Q_s is the ventilation volume due to wind infiltration.

The specific ventilation volume value is given by:

$$Q_v = \max[0.6V_h; Q_{vref}] \tag{3.5}$$

V_hVolume of living space [m^3/hr]; Q_{vref} *air* change volume in reference DTR C32

All the houses or flats surveyed do not have any type of mechanical ventilation, and they are naturally ventilated due to wind infiltration, which is, according to the national regulations, calculated by the following formula:

$$Q_s = \sum(Pe_v)[1/h] \quad [(m^3/h.m^2)] \text{ for 1 pressure difference of 1 Pa} \tag{3.5}$$

Where P is the permeability of the exposed facade to wind, e_v is the wind exposition coefficient roughness and are shown in table 3.3

Table 3.1 ev coefficient.

Hauteur H (1) (m)	Classes de rugosité (2)				
	V	IV	III	II	I
H ≤ 4	0,40	1,47	2,71	4,06	6,36
4 < H 7	1,10	2,30	3,51	4,82	7,08
7 < H 11	1,76	3,00	4,19	5,46	7,67
11 < H 18	2,57	3,87	4,97	6,17	8,32
18 < H 30	3,50	4,80	5,80	6,93	9,02
30 < H 50	4,47	5,78	6,66	7,71	9,72

Where wind exposition class I means very exposed buildings in sea side cities, class II when the building is less exposed as in rural unshielded area, airport, class III, shielded rural area, class IV urban zone, industrial zone wood, and finally class V big city center.

The flats and houses surveyed are of class III, IV, and V, and the mean high H is between 4m and 7m, for houses, and between 4m and 18m for flats. The heat loss by ventilation is mainly due to the poor quality of carpentry and doors seals and windows. None of the cases investigated in our survey have solar-reflective roofs, shade trees, urban vegetation or any kind of heat- island reduction as mentioned in reference [67].

More than 80% of Sétif area is fed with natural gas. 70% of the apartments are heated with natural gas stoves (convective air heater of different sizes with gas consumption of 1.05 to 1.75 Nm3/h and more).30%are equipped with central heatingsystems using a wall mounted central heatingboilerof 20 to 40 kW anddomestic hot water boilers of different sizes, more than 40% of the power is used for producing domestic hot water. Houses are divided into two main categories, detached and attached houses. The external building envelope of the attached and detached houses, and houses in line recently built in Setif are conceived in the same way as apartments (5 layers).Some houses in rural area are built with pressed earth blocks.

3.12 Conclusions and policy implications

After Algeria independence in 1962, the evolution of the electricity and gas sectors was, during the first few years, quite slow, but in the early seventies the sector experienced a significant growth reflecting the various development programs, which were launched. The expansion of the electric power grid, for the high and very high voltage, raised by 45.02%, between years1980-1990, 24.13% between 1990-2000, and 36.02%, between 2000-2010, for medium voltage, the expansion represents 53.65%, between years1980-1990, 34.47% between 1990-2000, and 21.75%, between 2000-2010, and for low voltage, 73.96 %, between years1980-1990, 40.67 % between 1990-2000, and 24.91%, between 2000-2010. While the rate of the population growth, between years1980-1990, was 25.40%, between years 1990-2000, was 17.73%, and between 2000-2010, it was16.21%. For gas penetration distribution, in the last decade, the localities connected to the natural gas reached 1369, raising the rate of natural gas penetration from 30.8% to 45.7%, and it is expected to reach 47.7% by the end of 2011, 49.5% by the end of 2012, 51.1% by the end of 2013, and 52.6% by the end of 2014.

Almost 71 locations are connected annually to natural gas during the last ten years against only 6 locations per year between 1962 and 2000. Transported gas bottles currently supply the rest of Algerian territory.The gas transport network has a total length of 10800 km;

the distribution network is almost 36900 km.

The electricity price for residential consumption, which is divided into two slices, jumped for 1 kWh consumed, from simple to nearly double, (from 0.935 DA in June 95 to 1.779 DA in April 2006,) the second slice unit price jumped from 1.609 to 4.179 DA, which is more than 2.5 times.

The natural gas unit prices, is also divided in two slices, and not only the unit price for both slices consumption, has increased, but the quantity of units allowed to the first slice, has been diminished by 2/3, this 2/3 has been shifted to the second slice unit price, so, someone, who has consumed 2000 units, would pay before the increase of the unit price, 1125*0.149= 167.63 DA for the first slice, and 875*0.295=258.13 DA for the second slice. After increase, he will pay 375*0.168= 63 DA for the first slide, and 1625*0.324= 526.5 DA for the second slice, with a total amount of 425.75 DA before the increase of the cost, and 589.5 after the increase, With a total percentage of 27.77% of increase, taxes followed nearly the same increase.The wise decision of fixing the unit price of gas and electricity consumption by law [69] stopped the price manipulation but the energy consumption is still growing.

Ambitious program to extend the electricity and gas network will solve many of the problems in disadvantaged rural areas, as well as the extension of the use of renewable energy alleviate environmental pollution.

The Algerian Building regulations as in the executive decree 2000-90 of April, the 24th, 2000 and the law 99-9 of July the 28th, 1999, in its articles 11 and 12 give the following directives, the new building owner or designer must be sure that the construction and the conception obey to the following principals:

-The thermal characteristics of newly constructed buildings must have the heat loss by thermal transmission through the building envelope, and ventilation, as required by DTR.

-The HVAC systems must have an automatic regulation, and, the thermal isolation characteristics of newly constructed building must obey to the following conditions:

- The heat loss calculated in winter must be less than a limit called reference loss, and, the heat gain calculated in summer must be less than the reference gain limit.

-The reference limits of heat loss and heat gain of newly constructed building are fixed by the DTR.

As it has been shown in the results, The value of the overall heat transfer coefficient a in the recommended regulation, for external walls and roofs in contact with outdoor air, for attached or detached houses, is bigger than the reference by 70% for climatic zone A, 48% for climatic zone B, and 100% for climatic zone C, with an over all average percentage of 73%. For floors, the overall heat transfer is more than the reference, by 5% for climatic zone A, -

0.1% for climatic zone B, and 8% more for Zone C, with an average increase of 2.9%. The over all averages percentage for walls, doors, and windows are respectively equal to 1.23%, 12,62%, and 0%.

The mean overall coefficient for all type of flats, in climatic zone A, for external walls, including roofs, was found to be 9.7% more than the reference value. For zone B it was found to be 21%, and for zone C 43%. While the same coefficient for floors was found to be 7.9% more in zone A, 4.1% more in zone B, and 7.5% more in zone C. Coefficient c and e, which represent the overall coefficient for walls, and doors remain the same without any variation recorded. For the d coefficient, which represents the heat transmission through the unit windows/door-windows, was greater than the reference value by 1.43% for climatic zone A, 4.28 % for climatic zone B, and 3.43% for climatic zone C.

These results show very clearly that the thermal regulation recommended by the DTR (coefficients a, b, c, d, and e) are far away to be respected in the surveyed houses and flats.

The external envelope of buildings needs to be more insulated, and DTR recommendations should be respected. More decisions for the application of the regulation should be taken before the final reception of –at least- the government project. The regulation itself should be updated; it seems that this regulation is the same as the French thermal regulation published after the 1973 oil crisis.

STUDY OF SPACE HEATING ENERGY CONSUMPTION IN TYPICAL RESIDENTIAL BUILDINGS

4.1 Introduction

In this chapter, comparison and analysis of the space heating for two multifamily five stories residential building is done, this kind of building, represents a large type of residential buildings in Riga, Building 7 Ledurgas iela, and building 9 Ledurgas iela, they were built during the soviet era in Riga, capital of Latvia.The largest number of building in one city in Latvia, and the largest number of buildings without retrofitting, they are typical buildings with heat supply systems for Eastern Europe. The energy consumption data for domestic hot water and space heating are collected from the utility services for these two buildings, for four years, from 2010 to 2013. The collected data for both buildings are compared to each other, and to the simulation results using one of the most used software in the field of building energy consumption, the eQUEST software. Monthly heating space energy consumption, between years 2010 and 2013, is compared to the simulated values given by eQUEST software. When the data to be inserted in the software, are missing, default values given by the software are used instead of the missing values. A comparison of the consumption of these buildings, and the simulation results given by eQUEST software and data collected from the annual energy consumption utility services in Riga has been carried out. Both building were affected the same default values when inserting the data in the software. The closeness of the simulation program with a real heat and energy flows in building was discussed, and conclusions drawn [**40**].

Although the price of oil are falling down by more than half these years, WTI crude oil fell 97.98 USD per barrel from 2013 to 55.35 USD in 2015, Brent crude oil fell down from 108.56 USD in 2013 to 60.53 USD in 2015, Meanwhile, during this period other type of fuels as gasoline, diesel, heating oil, natural gas, electricity and coal recorded a small change. As G7 during June 2015, pledges to phase out fossil fuels emissions this century, which is considered as positive step in tackling climate change, over 50 billion dollars were invested in oil and gas. Due to the political crisis between eastern and western countries, energy consumption is always increasing,wether oil price is going up or down. With the increasing cost of energy in general, and in the building in particular, which led to an increasing interest in energy efficient building design, and to this aim the entire building energy simulation programs are more and more employed in the first step in the design process to help architects and engineers to take the best decision, and to choose wathever alternatives design are more energy efficient and more cost effective.

Designed sustainable buildings should also fulfil all the operational requirements of the users. Researchers, practitioners and other stakeholders are faced with enormous challenges due to the need to recognize and take account of various dynamic processes around us, such as: global climate change, depletion of fossil fuel stocks, increasing flexibility of organizations, growing occupant needs and comfort expectation; increasing awareness of the relation between indoor environment and the health and well-being of the occupants, and consequently their productivity. Meanwhile, the use of airtight building materials to reduce infiltration from outdoor air is accompanied with a high level of indoor air pollutants. Several research works from the early 90s have brought up this problem to light [**20**]. Recent works [**69-70**], study the possibility of the introduction a hybrid ventilation systems in dwellings to try to control the ventilation rate while conserving thermal comfort conditions [**71**]. Indoor air quality and CO_2 emissions in nursery schools, the stack effect influence on air exchange rate in dwellings are developed in references [**72-74**] One of the most effective measures to save energy consumption in residential buildings is by increasing the thermal resistances of buildings' envelope as highlighted in references [**75-77**]. The rating of energy efficiency and sustainability of buildings by international standards such as American LEED, German DGNB, or Russian RGNB has a significant advantages of the construction at international level[**78**].These measures to increase energy efficiency should meet theinternational standard for sustainable buildings [**3,8]**. Entire building energy simulation tools are increasingly used for analysis of energy performance of buildings and thermal comfort of their occupants. A theoretical study of the whole building energy simulation is studied in reference [**79**]. The effect of existing energy infrastructure on climate change and future CO2 emissions is analysed in reference [**15**]. Nowadays, there are many building simulation programs with different user interfacesand different simulation engines that are capable of these analyses. The reliability of data exchange and straightforward, user- friendly interfaces are major aspects of the practical usage of the eQUEST software tools. Due to the huge amount of data that is to be input and the availability of rich 3D geometry rendering engines, effective data exchange and software interfaces are crucial to enable faster and reliable performance of the simulation tools [**36**]. Most of the building construction materials characteristics were taken from reference [**80**]. The effect of thermal insulation for different external walls' layers on energy savings is well discussed in ref. [**81**].

The software eQUEST is one of the most popular programs used by the building simulation community. Simulation can be performed within few minutes using a computer. A DOE-2 energy model takes less than a minute or two in case of a tertiary building to complete an annual simulation run. eQUEST efficiency results from its hour-by-hour calculations, and the sequential structure of LOADS-SYSTEMS-PLANT-ECONOMICS which does not solve the thermal dynamics of building envelope with the HVAC system operating performance simultaneously. [**38**]

EnergyPlus is a new generation simulation program built upon the best features of DOE- 2 and BLAST, and adds new modelling features beyond the two programs. With DOE-2's limitations in modelling emerging technologies, more modellers, especially in academia and research community, have begun using EnergyPlus for their simulation needs. EnergyPlus does sub-hourly calculations and integrates the load and system dynamic performance into the whole building energy balance calculations which can provide more accurate simulation results but runs much slower compared with DOE-2. [**38**].

Both the programs offer their own set of advantages and disadvantages. Other programs can be more or less close to one of these two major software, eQUEST and EnergyPlus. Theoretical analysis of some of these programs is detailed in previous researcher's works in the building energy simulation [**36-41**]. Recent study about the structural analysis of power consumption of similar buildings in Russia was carried out on the basis of the analysis of actual data of heat consumption.and they carried-out energy audit , to estimate conditions of systems of heating, power supply, and water supply [**82**].

4.2 Building description

The building concerned by the study and the comparison of the measured and simulated values of heat space energy consumption, is composed of five stories residential building in Riga, Latvia.

We refer to the building in Lēdurgas Street 7, by just building 7, and Lēdurgas Street 9, by just building 9. The volume of the building 7 is 9947 m^3, with a surface of 2072 m^2, and a length of 162.38m. The average flat's surface is 80 square meter. The volume of the building 9 is 9337 m^3, and with a surface of 2852m^2. The multi-family residential building studied is located in Riga, capital of Latvia. These types of buildings are called serija 103; they were built in the year 1969, during USSR period.

This kind of building is usually made of 5 to 6 floors, with ceiling and upper roof containing non heated space, bearing walls are constructed of self-supporting bricks, other walls are made of expanded clay panels, ceilings are made of concrete panels and roofs are matched. The building could have different length, and hence different surfaces. Each block has three flats in each level, studio, one bedroom flat and two bedroom flat, with the following respectively surfaces, 34.94 m^2, 57.75m^2, and 73.6m^2. All the selected buildings have the same facades orientation.

More details about external envelope building material and insolation are given in latvian refrence (Ēku siltumefektivitātes paaugstināšana) published in Riga, in 1999 by building departments [**83**].

The simulation is performed using eQUEST software Version 3.64, using the following data project name, the name of the street, the building type, multi-family mid-rise building, the weather data file for Latvia is used, the building area is introduced in feet, the number of levels, and the heating equipment is heating coil, the years 2010, 2011, 2012, and 2013 were chosen respectively.

The roof surfaces construction chosen is wood standard frame, wood frame, 50.8x152.4, 406.4mm. o.c. The externel finish and color, roof build-up, and above grade walls have a medium absorption of 0.6. Insulation for the roof, above grade wall insulated with 322.5mm fiber bed sheeting (R-13) [2.29 m^2K/W], added insulation for the roof R-38 batt [6.87m^2K/W], with no rad barrier, and for above grade wall R-19 [3.34m2K/W] batt, with no interior insulation.

For the ground floor, the values taken are exposure over parking garage, no concrete cap, carpet with fiber pad, construction 152.4mm concrete, external/cav insulation 127mm, polyurethane (R-30) [5.30m^2K/W], slab edge insulation – no board insulation, with no interior board insulation, and with no finish for slab edge.

Ceiling interior finish is chosen as dry wall finish with no ceiling insulation, vertical walls are of the typeframe, no wall insulation. Floor interior finish is chosen carpet with fiber pad, construction 25.4 mm plywood underlayment, no concrete cap, and no board rigid insulation.

Main door dimensions are 2.011m high and 1.83m width , with double low.E, glass category double low E (e3=0.2) clear a 6.35mm,12.7mm Air(2614), frame type Alu with a frame width of 76.2mm. Secondary doors dimensions are taken 2.011m, and 0.914 m construction type, steel hollow core.

Exterior windows, only one type of windows is described with glass category double Low-E, type (e3=.2), clear 3.17mm, and a 6.35mm Air(2610), frame type insulated with fiber-glass/vinyl, oper, Mtl spacer, frame width = 38mm, windows dimensions high is taken 90.42mm, sill high with 76.2mm, and percentage of window from total surface (floor to ceiling), for all orientations, is taken 20%, with no exterior windows shade. Roofs have no skylight.

The building operation schedule for entire year from the 1st January to 31 of December is represented for the whole week as the following: from Monday to Friday, return at 5 pm, and leave at 7 am, for Saturdays, Sundays and holidays, leave at 9 am and return at 4 pm, day time the flats are supposed to be not occupied. Activity area allocations, percent area for multi-family, corridor storage, together with a maximum occupation and ventilation rate are chosen according to the table 4.1.

Table 4.1Ventilation rate for the studied building

	Percent Area%	Max Occupation m^2/person	Ventilation m^3hr^{-1}/person
Residential (Multi-family dwelling)	71	57,9696	50,97
Corridor	16	92,9	84,95
Storage	7	46,45	127,425
Laundry	6	18,58	42,475

Interior end-uses contributing to space load are interior lighting, cooking and miscellaneous equipment, exterior end-uses not contributing to space load are external lighting and domestic hot water. Interior lighting is taken as 5.32W/m^2 for the residential dwelling, 6.13W/m^2 is taken for the corridor, 12.8W/$m^2$for storage, and 137.7W/m^2 for laundry , cooking loads profile for gas or electric cooker are not taken in consideration. For heating primary equipment, hot water loop head is taken as11.15m and design DT is taken 4.44°C, hot water loop flow is taken constant, with a single pump, water is supposed to be heated by natural gas, the boiler efficiency is 80%. The hot water system schedule for the entire year is following the operation schedule, from Monday to Friday, return at 5 pm, and leave at 7 am, for Saturdays, Sundays and holidays, leave at 9 am and return at 4 pm, the set value is fixed at 82.2°C.

For the residential domestic hot water is modelled using a value of 75.8 litre/person/day, according to the data given by the Latvian authority which is an average of 105 litres per day, with an input rating value of 588.38 kW, and with a thermal efficiency of 0.8. The water supply temperature is 43.33°C.

The simulation results for electrical energy consumption are given in MWh, but for space heating and domestic hot water, the simulation results are given for gas consumption by one million Btu, and converted to kWh.

As the subject of our research deals only with space heating and domestic hot water, the results of energy consumption for our residential multi-family building given by the utility service Latvinergo are given in MWh, thus the value of gas consumption given by the simulation in Btu are converted to MWh to have the same units and comparison can, then, be made. The architecture measurement of the residential building, are also converted from meter to feet, to be fitted in the software. An example of the simulation results, building 7 and building 9 Lēdurgas Street, for the year 2010 are summarized in the following table 4.2.

Table 4.2 Summary of the simulation results

	Building 7		Building 9		Closiness %	
	Mea. MWh	Sim. MWh	Mea. MWh	Sim. MWh	Building 9	Building 7
Jan-10	89.77	73.43	97.47	94.57	97.02	81.8
Feb-10	65.17	55.34	73.86	70.87	95.95	84.91
Mar-10	46.93	47.4	58.4	60.32	103.29	101.01
Apr-10	24.2	29.22	33.83	37.03	109.46	120.76
May-10	9.2	10.87	18.54	13.59	73.30	118.12
Jun-10	8	4.58	16.6	5.58	33.61	57.27
Jul-10	6.9	1.03	14.97	1.05	7.01	14.9
Aug-10	7.2	3.03	14.93	3.43	22.97	42.02
Sep-10	8.3	8.19	16.79	9.92	59.08	98.73
Oct-10	28.6	33.07	33.5	41.7	124.48	115.64
Nov-10	48.8	55.39	56.4	70.96	125.82	113.51
Dec-10	76.05	65.76	81.7	84.5	103.43	86.47
Mean	34.93	32.28	36.27	34.09	93.96	86.26

The weather data for Latvia, and the residential building architecture details, and type of building materials were inserted in the software eQUEST, when data to be fitted in the software are missing, we used the default values given by the simulation software. Simulation of energy consumption for each year was performed, and the results of simulation and measured values for Lēdurgas street number 7 for the year 2011 are plotted together in the figure 4.1.

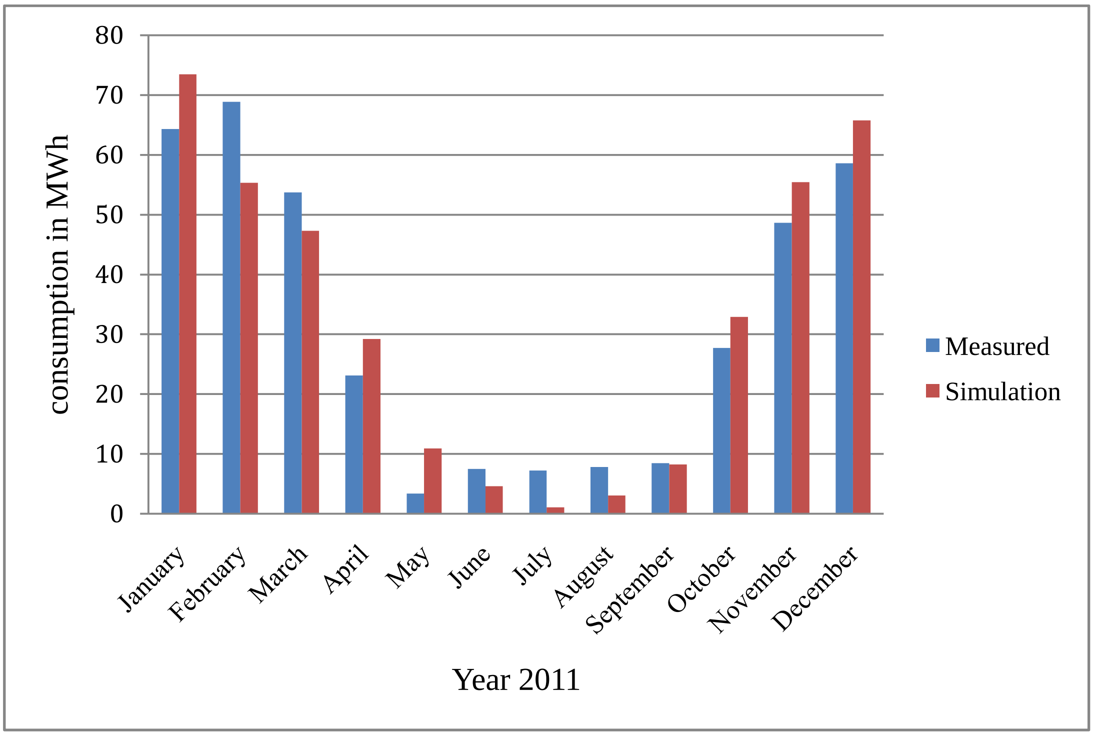

Figure 4.1 Space heating energy consumption for Lēdurgas building 7, year 2011.

Simulation of energy consumption for each year was performed, and the results of simulation and measured values for Lēdurgas street number 9 for the year 2011 are plotted together in figure 4.2.

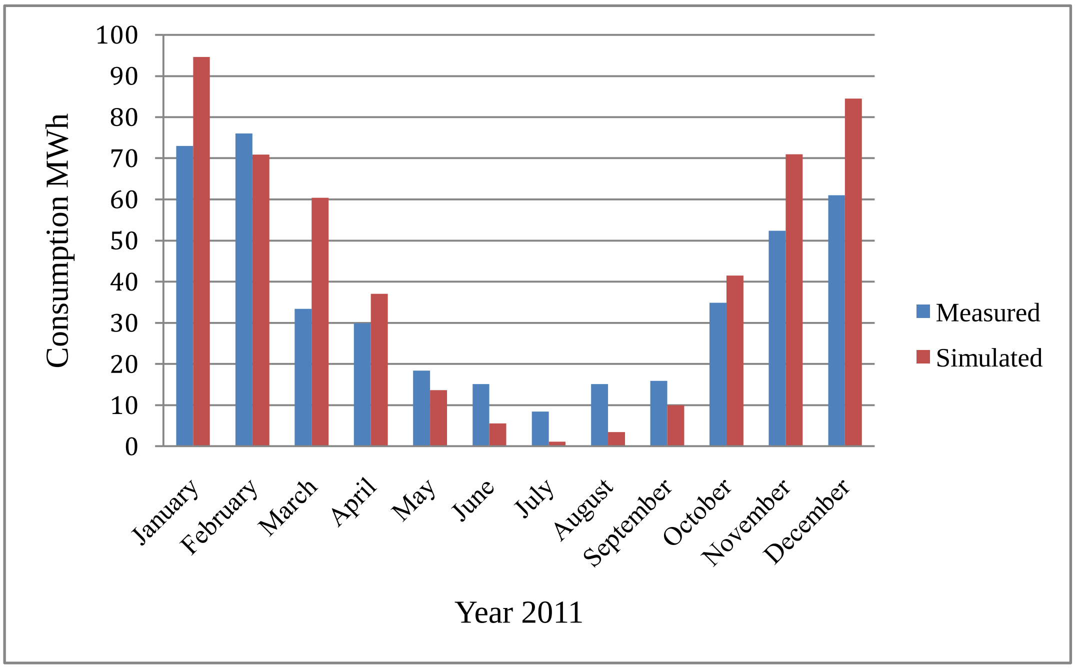

Figure 4.2 Space heating energy consumption for Lēdurgas building 9, year 2011.

Comparison between the energy consumption of building 7 and building 9 and results of their simulation for the period of 2010 till 2013, have been made, example of these results for the year 2011 are shown in figure 4.3.

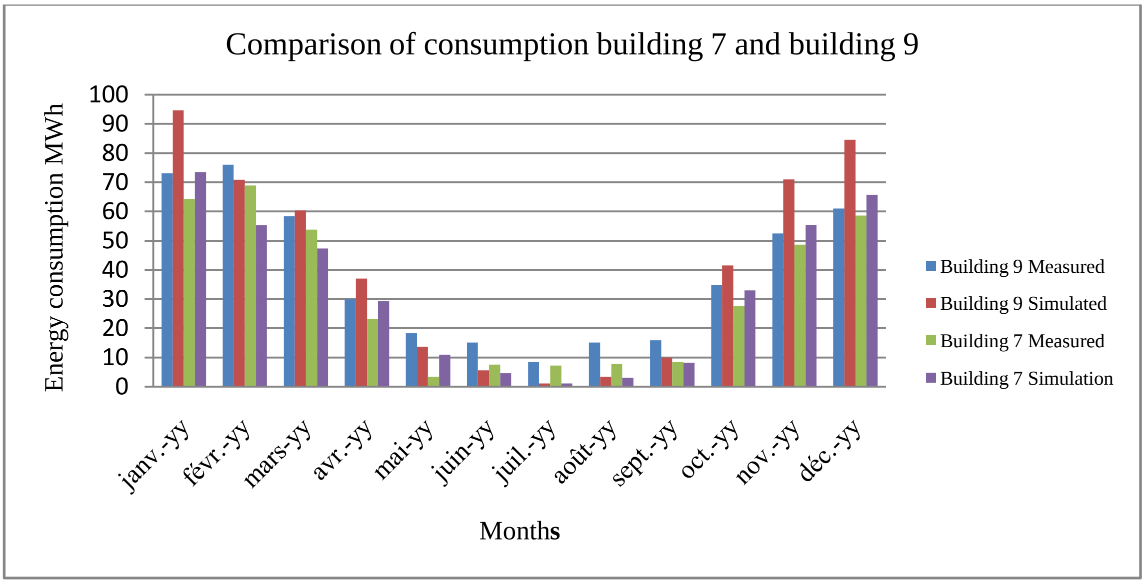

Figure 4.3 Results comparison between consumption building 7 and building 9.

The following tables give a sample of the results of the measured and simulated values for years 2010-2013, for the building situated at Lēdurgas street,7. Table 4.2.

Table 4.2 Measured and simulated values, Lēdurgas 7, 2010-2013

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lēdurgas 7 Year 2010	Measured	89.77	65.17	46.93	24.20	9.20	8.00	6.90	7.20	8.30	28.60	48.80	76.05
	Simulated	73.43	55.34	47.40	29.22	10.87	4.58	1.03	3.03	8.19	33.07	55.39	65.76
Lēdurgas 7 Year 2011	Measured	64.32	68.89	53.73	23.10	3.38	7.51	7.21	7.82	8.48	27.72	48.66	58.58
	Simulated	73.49	55.34	47.32	29.19	10.93	4.61	1.06	3.03	8.22	32.92	55.42	65.76
Lēdurgas 7 Year 2012	Measured	78.99	57.95	61.66	28.39	8.79	7.00	7.02	6.82	8.30	29.82	47.23	56.26
	Simulated	73.43	55.42	47.17	29.14	10.84	4.64	1.03	2.97	8.37	33.04	55.28	65.70
Lēdurgas 7 Year 2013	Measured	78.99	57.95	61.66	28.39	8.79	7.00	7.02	6.82	8.30	29.82	47.23	56.26
	Simulated	73.28	55.45	47.35	28.84	10.75	4.64	1.03	3.03	8.46	33.51	55.04	65.82

3.3 Results

As usual, space heating energy consumption is very high in winter time in most countries, but is harder in Baltic states, in Latvia, the space heating together with domestic hot water consume more energy than all other applications in the residential building, especially in old buildings built during the soviet era. The highest level of consumption according to data given by the Latvian utility for space heating in Riga, and for building 7, for the year 2011, is recorded in January, in the second place comes December, and close to it is February. The difference between the measured value and simulated value for January for the year 2010, is equal to 16.34 MWh, for December is equal to 10.28MWh, and for February is 9.83 MWh, for March the difference is -0.5 MWh, in April the value is higher than the measured one by a value of -5 MWh.

The difference between the measured value and simulated value for january for the year 2011 is -14.66 MWh, it is the only negative value for the month of january during our study period 2010-2013, this means that the simulated value exceeds the recorded value, and it is due to some work which had been done on the district heating system during that month, for December, the difference is equal to 2.32MWh, and for February is 10.93 MWh. The difference between the measured value and simulated value for january for the year 2012, 2013 is equal to 5.56 MWh and 5.70MWh, for December, and it is negative and it is respectively equal -9.54 MWh and -9.56MWh, and this could be explained by some work which could be done on the distribution network of the district heating system of Riga during the months of October, November, and December where all the simulated values exceed the recorded ones. For February 2012, and 2013, it is respectively equal 2.52 MWh, 2.49 MWh.

The highest level of consumption for building 9, for the year 2011, is recorded in January, in second place comes February, and close to it is December. The difference between the measured value and simulated value for January for the year 2011, is equal to 2.90 MWh, for February is equal to 3.01MWh, and for December is -2.8 MWh, for March the difference is -1.92 MWh, in April the value is higher than the measured one by a value of -5 MWh.

It has been observed that the energy consumption for heating space during the four year measurements for both buildings was less than the simulated ones. Meanwhile, in February and March, both measured building heat space consumption was bigger than the results given by simulation. For October, November, and December, amount of heat measured was bigger than the amount found by simulation for the period of 4 years, from 2010 to 2013.

The difference between the measured value and simulated value for space heating season for the years 2010, 2011, 2012, and 2013 for building number 7 and building number 9 are summarised in the table 4.3. The mean heat space energy consumption by kWh/m^2 also is calculated for both buildings investigated and results are summarized in table 3.3, for the period of 2010-2013.

Table 4.3 Measured and simulated values, and consumption in kWh/m^2

		Jan.	Feb.	Mar.	Sep.	Oct.	Nov.	Dec.	kWh	kWh/m^2
Lēdurgas 9	Measured	97.47	73.86	58.40	16.80	33.50	56.40	81.71	418140.00	146.61
Year 2010	Simulated	94.57	70.87	60.33	9.93	41.71	70.96	84.50	432870.53	151.78
Lēdurgas 7	Measured	89.77	65.17	46.93	8.30	28.60	48.80	76.05	363620.00	175.49
Year 2010	Simulated	73.43	55.34	47.40	8.19	33.07	55.39	65.76	338589.46	163.41
		Jan.	Feb.	Mar.	Sep.	Oct.	Nov.	Dec.	kWh	kWh/m^2
Lēdurgas 9	Measured	73.03	76.06	58.33	15.84	34.85	52.41	61.02	371539.99	130.27
Year 2011	Simulated	94.60	70.87	60.36	9.99	41.50	70.99	84.53	432841.16	151.77
Lēdurgas 7	Measured	64.32	68.89	53.73	8.48	27.72	48.66	58.58	330380.00	159.45
Year 2011	Simulation	73.49	55.34	47.32	8.22	32.92	55.42	65.76	338471.98	163.36
		Jan.	Feb.	Mar.	Sep.	Oct.	Nov.	Dec.	kWh	kWh/m^2
Lēdurgas 9	Measured	71.65	79.02	54.05	15.60	42.74	56.59	77.27	396920.00	139.17
Year 2012	Simulated	94.49	70.90	60.12	10.16	41.62	70.81	84.47	432576.82	151.67
Lēdurgas 7	Measured	78.99	57.95	61.66	8.30	29.82	47.23	56.26	340210.00	164.19
Year 2012	Simulated	73.43	55.42	47.17	8.37	33.04	55.28	65.70	338413.24	163.33
		Jan.	Feb.	Mar.	Sep.	Oct.	Nov.	Dec.	kWh	kWh/m^2
Lēdurgas 9	Measured	81.96	60.99	67.74	15.78	38.82	52.29	61.47	379050.00	132.91
Year 2013	Simulated	94.34	70.99	60.24	10.28	42.21	70.58	84.65	433281.73	151.92
Lēdurgas 7	Measured	78.99	57.95	61.66	8.30	29.82	47.23	56.26	340210.00	164.19
Year 2013	Simulated	73.28	55.45	47.35	8.46	33.51	55.04	65.82	338912.55	163.57

The mean values of simulated and measured energy consumption, for the seven building chosen, are illustrated in the table 3.4, these results show that the simulated and the measured values are different.We can see from table 3.4, that for the building situated at Lēdurgas 9, for the years, 2010, 2011, 2012, and 2013, all the mean measured values are smaller than the mean simulated ones. For the Lēdurgas 7, in the contrary of the Lēdurgas 9, all the measured values are higher than the simulated ones. For the buildings in Mores street 7, 5 and 3, the simulated values of the years 2011, 2012 and 2013, are higher than the measured ones, but for the year 2010, the mean measured value is bigger than the mean simulated value. For Ostas building 4 and 6, all the simulated values for the whole period considered 2010 to 2013, are bigger than the measured values.

The mean values for the measured, are smaller than the simulated values, for the years 2010 to 2013, for the buildings situated in Lēdurgas 9, Mores7, 5, and 3, and Ostas street 4, and 6.The only building where the mean measured value is higher than simulated one is Lēdurgas 7. The overall average final results for the 4 years analysed, the mean measured value is smaller than the simulated.

Table 4.4 Mesured and simulated mean value in kWh/m^2

		2010	2011	2012	2013	Mean Meas.	Mean Sim.
Lēdurgas 9	Measured	146.61	130.27	139.17	132.91	137.24	
	Simulated	151.78	151.77	151.67	151.92		151.79
Lēdurgas 7	Measured	175.49	159.45	164.19	164.19	165.83	
	Simulated	163.41	163.36	163.33	163.57		163.42
Mores 7	Measured	151.10	132.05	132.99	132.99	137.28	
	Simulated	150.31	150.28	150.21	150.44		150.31
Mores 5	Measured	150.11	113.84	133.45	124.94	130.59	
	Simulated	150.49	150.47	150.41	150.60		150.49
Mores 3	Measured	169.13	150.61	160.33	145.08	156.29	
	Simulated	164.35	164.33	164.26	164.47		164.35
Ostas 4	Measured	160.28	133.83	141.76	139.82	143.92	
	Simulated	161.11	161.11	161.05	161.32		161.14
Ostas 6	Measured	152.29	131.83	137.90	133.68	138.92	
	Simulated	153.96	153.97	153.93	154.16		154.00
Overall average						144.30	156.50

The results of the overall mean value of calculated percentage of closeness of simulated and measured values for the heating season, show that, the closest value appeared in the month of February with nearly 100%, followed by the month of October with 98.77%, and March by 96.08, then the months of November and December by respectively 93.43%, and 89.25%, and for January, it was found to close by 84.58%. The detailed results are summarised in table 3.5.

Table 4.5 Closeness percentage measured and simulated values

	Period	Jan.	Feb.	Mar.	Sep.	Oct.	Nov.	Dec.
Lēdurgas 9	2010	97.03	95.95	103.30	59.09	124.50	125.82	103.42
	2011	77.20	107.32	96.64	158.62	83.97	73.83	72.19
	2012	75.83	111.45	89.90	153.51	102.69	79.91	91.48

	2013	86.88	85.91	112.45	153.50	91.98	74.09	72.62
Lēdurgas 7	2010	81.80	84.91	101.01	98.73	115.64	113.51	86.47
	2011	87.53	124.50	113.55	103.11	84.19	87.80	89.08
	2012	92.96	95.64	76.50	100.85	110.81	117.04	116.78
	2013	92.77	95.69	76.79	101.91	112.38	116.54	116.99
Mores7	2010	89.62	94.22	94.72	50.10	114.18	129.65	106.10
	2011	76.52	106.01	98.09	177.78	95.13	78.99	71.35
	2012	85.47	84.56	107.95	174.79	102.35	76.62	74.27
	2013	85.58	84.41	107.77	173.50	101.07	76.87	74.12
Mores5	2010	87.79	96.19	90.76	62.38	113.69	139.81	104.93
	2011	76.57	105.65	30.91	158.91	84.44	73.51	69.11
	2012	74.41	111.60	87.67	144.16	96.61	72.84	89.06
	2013	84.32	81.89	102.53	152.93	88.73	72.02	66.18
Mores3	2010	86.21	93.79	103.63	59.03	97.60	121.09	100.82
	2011	80.64	117.79	100.11	156.78	90.41	78.95	79.59
	2012	85.44	120.75	96.30	161.54	108.67	78.46	95.63
	2013	88.41	86.15	110.24	148.79	87.49	76.65	76.69
Ostas4	2010	85.59	101.06	107.80	68.46	102.26	124.90	103.30
	2011	75.86	103.80	97.92	130.74	80.65	71.15	68.30
	2012	73.04	107.40	88.05	137.20	96.14	72.56	91.10
	2013	87.29	86.23	110.20	148.33	93.70	73.10	69.30
Ostas6	2010	76.06	100.03	111.53	63.39	106.20	133.33	110.48
	2011	88.25	105.11	92.70	151.57	81.96	68.92	69.39
	2012	90.93	106.80	83.38	141.47	91.23	71.14	86.39
	2013	98.33	125.85	97.97	71.50	106.94	136.91	143.94
	Mean	84.58	100.74	96.08	123.67	98.77	93.43	89.25

4.4 Conclusions

The shape slope of the curve of measured values given by the utility services follows closely the slope of the simulated curve. The recorded (measured) values for the winter months (December, January, February), and summer time (June, July, August) are higher than the simulated values, but for the rest of the months, the simulated values are higher than the measured values. The mean recorded value of space heating consumption for building 7 for 2010, is equal to 34.93MWh, and the simulation gives a mean value of 32.28 MWh, with a difference of 2.65 MWh, which means that the results of simulation is close to the measured values by 86.26%. In January the simulation results are closed to recorded results by 81.79%, for February they are closed by 84.90%, and for December they are closed by 86.47% as shown in table 3.5.

The mean recorded value of space heating consumption for building 9 for 2010, is equal to 36.27MWh, and the simulation gives a mean value of 34.09MWh, with a difference of 2.18 MWh, which means that the results of simulation is close to the measured values by 93.96%. In January the simulation results are closed to recorded results by 97.02%, for

February they are closed by 95.95%, and for December they are closed by 93.96%.

The average heat space energy consumption for cold season (January, February, March, October, November December) in kWh/m2, for building 9, was found to be 146.61 in year 2010, 130.27 in 2011, 139.17 in 2012, and 132.91 in 2013, with an average of 137.24 for the period of 4 years between 2010 and 2013. Simulated values for the same building were found to be 151.78 in year 2010, 151.77 in 2011, 151.67 in 2012, and 151.92 in 2013, with an average of 151.79 for the period of 4 years between 2010 and 2013.

The average heat space energy consumption for cold season (January, February, March, October, November December) in kWh/m2, for building 7, was found to be 175.49 in year 2010, 159.45 in 2011, 164.19 in 2012, and 164.19 in 2013, with an average of 165.83 for the period of 4 years between 2010 and 2013. Simulated values for the same building were found to be 163.41 in year 2010, 163.36 in 2011, 163.33 in 2012, and 163.57 in 2013, with an average of 163.42 for the period of 4 years between 2010 and 2013.

It was also noticed that the mean measured values for building 9 were found to be smaller than the average simulated values during the period 2010-2013, with an average closiness percentage of 90.42%. Meanwhile, for building 7, for the same period, the mean simulated values were found to be smaller than the measured ones with an average closeness percentage of 98.54%.

The closeness percentage of the recorded value of space heating energy consumption and the simulated value performed by the eQUEST simulation software, version 3-64, for the multi-family residential building located at Lēdurgas street number 7 Riga, was found to be 93.12% for the year 201, 102.45% for the year 2011, 99.47% for the year 2012, and 99.62 for the year 2013, with an average of 98.54%. The closeness for Lēdurgas street number 9, was found to be 96.60% for the year 201, 85.84% for the year 2011, 91.76% for the year 2012, and 87.48 for the year 2013, with an average of 90.42%.

Due to the contradictory results between the two buildings which are located in the same area, and with the same architecture, but with different volume, the mean recorded values for building 9 were smaller than the simulated mean, while the contrary is observed with building 7, more investigation with a greater number of buildings is expected to give more information about this controversial results.

Results of the overall mean value of calculated percentage of closeness of simulated and measured values for the heating season, show that, the closest value appeared in the month of February with nearly 100%, followed by the month of October with 98.77%, and March by 96.08, then the months of November and December by respectively 93.43%, and 89.25%, and for January, it was found to be close by 84.58%.

According to the ENCERB report for building energy certification directives, the analysis of buildings' heat consumption had shown that the mean total annual specific heat consumption of buildings in Ogre town (Latvia) in year 2003/2004 was 176.16 kWh/m^2, with a mean annual specific heat consumption for space heating of 102,78 kWh/m^2 and the part of space heating in total heat consumption was 0.59. In order to get more precise results showing buildings' full energy consumption, the new analysis of heat consumption was done only for those buildings, which have all three parts of energy consumption – heat, gas and electricity consumption. The adjusted calculation showed that annual specific heat consumption for space heating is 104.39kWh/m^2 and for hot water supply – 73.30kWh/m^2. Meanwhile, the annual space heating consumption for Lēdurgas street building number 9 was found to be equal to 146.61kWh/m^2 for years 2010, 130.27 kWh/m^2 for year 2011, 139.17 kWh/m^2 for year 2012, and 132.91 kWh/m^2 for 2013, with a mean value of 137.24 kWh/m^2. The same results for building number 7 was found to be equal to 175.491kWh/m^2 for years 2010, 159.45 kWh/m^2 for 2011, 164.19 kWh/m^2 for 2012, and 164.19 kWh/m^2 for 2013, with a mean value of 165.83 kWh/m^2. The respective percentage of closeness for the building 9 is 96.6% for year 2010, 85.84% for year 2011, 91.76% for year 2012, and 87.48% for year 2013, and with an average of 90.42%, and for the building 7 is 93.12% for year 2010, 102.45% for year 2011, 99.47% for year 2012, and 99.62% for year 2013, and with an average of 98.5%.

The average energy consumption for the heating season in kWh/m^2, for the four years analysed, have a value of 137.24kWh/m^2, and a simulated value of 151.79kWh/m^2, for Lēdurgas 9, 165.83kWh/m^2, and 163.42kWh/m^2 for Lēdurgas 7, 137.28kWh/m^2, and 150.31kWh/m^2 for Mores7, 130.59 kWh/m^2, and 150.49 kWh/m^2 for Mores5, 156.29 kWh/m^2 and 164.35 kWh/m^2 for Mores3, 143.92 kWh/m^2 and 161.14 kWh/m^2 for Ostas4, and finally 138.92 kWh/m^2 and 154 kWh/m^2 for Ostas6. The overall average for the seven buildings, and the four years, have a value of 144.3 kWh/m^2 as a measured value, and 156.50 kWh/m^2 as a simulated value.

THEORETICAL MODELS OF RESIDENTIAL BUILDINGS ENERGY CONSUMPTION

5.1 Introduction

The residential building energy consumption RBEC is defined as the energy consumed by households, excluding transportation uses. In the residential sector, energy is used for equipment and to provide heating, cooling, lighting, Energy consumption is affected by income, energy prices, as well as by building location, household characteristics, weather, type and efficiency of equipment, energy access, availability, and energy related policies. As a result, the type and amount of energy can vary widely within and across regions and countries

In recent years, although the measurements and policies which has been taken to reduce energy consumption and gas emissions, and though the residential buildings have continuously improved in efficiency, substantial differences in residential sector energy consumption is still being observed in similar dwellings [**84-85**]

World residential energy consumption represents 16-50% and averages approximately 30% worldwide. In the United States, residential sector approximately accounts for 21.2% of total energy consumption of year 2012 (EIA 2014). Only 10% of the population of the world exploits 90% of fossil fuel resources. Today's energy systems rely heavily on fossil fuel resources diminishing ever faster. The world must prepare for a future without fossil fuels. Sustainable energy consumption has become urgent matter for all countries. World residential delivered energy consumption increases by 57% from 2010 to 2040 (Table 1.1).

In Europe the built environment consumes 40% of the produced energy. A large of this energy is consumed in residential buildings. Households account for about 30% of the total building-related energy consumption in OECD countries [**11,37**]. As 30-57% of the energy consumed by households is spent on space and domestic water heating, conservation in this area is a matter of vital importance [**84**]

This significant consumption level indicates the crucial role that residential sector plays in total energy consumption, which means that it is necessary to understand the characteristics associated to energy consumption to better prepare for the increasing energy demand in the future.

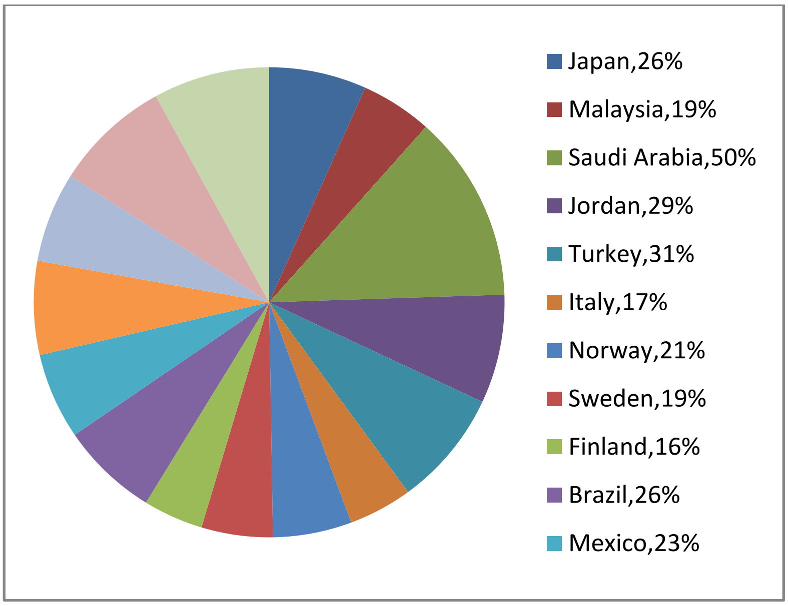

Fig. 5.1: Residential energy consumption shown as a percentage of national energy consumption and in relative international form [**25**].

In response to climate change, high energy prices, and energy supply/demand, there is interest in understanding the detailed consumption characteristics of the residential sector in an effort to promote conservation, efficiency, technology implementation and energy source switching, such as to on-site renewable energy. [**25**]

The other sectors such as commercial, agriculture, transport and industry have a regular energy consumption because of their owners, usually these sectors are private or under centralized ownership and they are well defined and regulated. The energy consumption in the residential sector is very complex because of the large variety of construction types, sizes, thermal envelope materials, the very wide variety of occupant behavior that have an impact on the energy consumption.

Space heating, space cooling, domestic hot water, appliances, and lighting are the major equipments that consume the most of energy in residential buildings. The residential energy consumption depends on a large number of variables such as, climate zone, dwelling characteristics, occupant behavior, life standard, energy price, and incomes. It is meant by total residential energy consumption (REC), the energy required to stand all the energy consumed by the aggregates, including the losses due to energy transmission or appliances efficiencies. The energy consumed for heating and cooling space has the biggest share of the total REC. This energy can be supplied with different sources of energy including passive solar gain, occupants gain, lighting and appliances gain. The total REC for a given area or a country gives the regional or national residential sector consumption. The modeling techniques of the REC are reviewed in this part.

The mean object of the building energy consumption modeling is to quantify the energy needs and requirements as a function of input parameters. The most common reason for using models is to determine the regional and national energy supply requirements at a large scale, and the change in energy consumption in a dwelling due to renovation, retrofit, or improvement of equipment at a local scale. Modeling REC can be very useful for policy makers and householders to make better decision that may support energy supply, retrofit and technology incentives, and building codes and so on.

REC models depends on the climate variations, thermal zone, building construction, neighborhoods, city or a village, state or province, level of standard life, region or nation. In this chapter we review the residential sector energy consumption models and introduce the modeling techniques, review the previous literature works, and as a conclusion an analysis of the strengths and weaknesses of the techniques.

The objective is to provide an up-to-date review of different modeling techniques used for modeling residential building energy consumption. Two main approaches are identified: top-down and bottom-up. Each method depends on different levels of input data information, different calculation or simulation techniques, and shows results with different applicability. A detailed review of each technique, focusing on the strengths, shortcomings and purposes, is provided along with a review of models reported in the literature.

5.2 Overview of modeling methodologies.

In this section we intended to outline a description of the methodologies and to underline techniques available for modeling residential sector, as this has already been given elsewhere [**35,85**]. Residential energy models strongly depend on input data from which to calculate or simulate energy consumption. The level of detail of the available input data can vary dramatically [**42**], resulting in the use of different modeling techniques which seek to take advantage of the available information. These different modeling techniques have different strengths, weaknesses, capability, and applicability. The input data necessary to build residential energy models includes information on the physical characteristics, occupants and their appliances, historical energy consumption, climatic conditions, and macroeconomic indicators of the dwellings, depends on the modeling methodology to be used. The preliminary estimate of the total residential sector energy consumption is usually published by governments which compile gross energy values submitted by energy providers (examples are Canada [**86**], USA [**87**], UK [**88**], and China [**90**])These energy estimations give a good indicator for energy consumption but may not accurate as they do not take in account the onsite energy gain or generation. A more detailed source of energy consumption data, typically on a monthly basis and for each dwelling, is the billing records of energy suppliers(e.g. monthly dwelling electricity bill). However, with no additional housing information these energy consumption values are difficult to correlate due to the wide variety of dwellings and occupants. Housing surveys are conducted to provide more detailed information about equipments energy consumption values. The target of these surveys is a sample of residential dwellings to determine building properties and occupant characteristics and appliances penetration levels (examples are Canada [**90**], USA [**91**], and UK [**92**]).

Usually, surveys aim to define the physical properties of the house such as the geometry, and thermal properties of the envelope, ownership of appliances, occupants and their use of appliances and preferred settings, and demographic characteristics. In addition, surveys may attempt to obtain the energy suppliers' billing data (described above) and alternative energy source information (e.g. unreported wood usage) to correlate the energy consumption of the house with its characteristics identified during the survey. This will permit the calibration through reconciliation of a model's predicted energy consumption with actual energy billing data. This level of information is superior to the previously mentioned energy supplier values; however, it is limited due to collection difficulties and cost, and therefore it is imperative that the selected sample be highly representative of the population. Also, occupant descriptions of their appliance use are highly subjective and can be influenced by the season during which the survey takes place [**90**]. Examples of surveys which have been condensed for the purpose of energy simulation are [**93,94**].Estimated total sector energy, individual billing data, surveys, and sub-metering have been used to varying degrees in the development of residential energy consumption models. The determination of which information is used depends on availability and model's purpose. The purpose of models ranges widely and may be directed towards determining supply requirements, price and income elasticity, and the energy consumption impacts of upgrades technologies or changes to behavioural patterns.

5.3 Techniques to model energy consumption.

Most of researchers group the techniques used to model residential energy consumption into two categories, ''top-down'' and ''bottom-up''. Broadly, there are two fundamental classes of modelling methods used to predict and analyze various aspects of the overall building stock energy use top-down and bottom-up approaches [**95**]. . Fig. 1, as developed by IEA [**96**], schematically displays the general methodological philosophy behind the bottom-up and top-down models and their main characteristics are described in Table 5.1.

Table 5.1 Benefits and limitations of top-down and bottom-up modeling approaches

Characteristics Top-down		Bottom-up statistical	Bottom-up building physics
e nefits	- Focus on the interaction between the energy sector and the economy at large -Capable of modeling the relationship between different economic variables and energy demand. -Avoid detailed technology descriptions. - Able to model the impact of different social cost-benefit energy and emissions policies and scenarios. -Use aggregated economic data. - long term forcasting in the absence of any discontinuity -Inclusion of macroeconomic and socioeconomic effects. -Simple input information. -Encompasses trends.	-Include macroeconomic and socioeconomic effects -Able to determinate a typical end-use energy consumption -Easier to develop and use -Do not require detailed data (only billing data and simple survey information) -Encompasses occupant behavior. -Determination of typical end use energy contribution -Inclusion of macroeconomic and socioeconomic effects. - Uses billing data and simple survey information	-Describe current and prospective technologies in detail -Use physically measurable data -Enable policy to be more effectively targeted at consumption -Assess and quantify the impact of different combination of technologies on delivered energy -Estimate the least-cost combination of technological measures to meet given demand - ground up energy estimation -Determination of each end use energy consumption by type and rate -Determination of end use qualities based on simulation
L imitations	-Depend on past energy economy interactions to project future trends -Lack the level of technological detail -Less suitable for examining -Technology-specific policies - Typically assume efficient markets, and no efficiency gaps -Reliance on historical consumption information	-Do not provide much data and flexibility -Have limited capacity to assess the impact of energy conservation measures -Rely on historical consumption data - Require large sample -Multicollinearity	-Poorly describe market interactions -Neglect the relationships between energy use and macroeconomic activity -Require a large amount of technical data -Do not determinate human behavior within the model but by external assumption -Assemption of occupants behaviour

However, it is also the case that some of the more sophisticated models can combine components where each of these approaches has been used.

5.4 Variations of residential energy use characteristics.

A variety of variations exist in residential energy use characteristics, such as occupant behavioral pattern, and efficiency standards of equipment, making it challenging to accurately estimate the breakdown of energy use. A previous research explored both qualitative and quantitative effects of occupancy and behavioral on residential energy use (Seryak and Kissock 2003), which focused on the residential homes owned by University of Dayton (UD). For the electricity use, influence factors include:

1-Number of occupants: Electricity use is positively correlated with the number of occupants per household, that is, the greater number of occupants a household has, the higher the electricity use is. But electricity consumption per capita tends to decrease sharply as the number of occupants increases.

2-Time of occupancy: Electricity consumption differs and is un-evenly distributed in each period of a year. Electricity use tends to peak at summer and winter because of the great demand for space cooling and heating, households near college usually have lower energy consumption in June due to the summer break, while they also face a sharp increase in

September, when students start classes.

3-Occupant behavior: Even in the situation where some of the energy use characteristics are identical in two households, other variations may still lead to a big difference in electricity use, among which occupant behavior plays a crucial role in controlling the electricity bill.

Occupant behaviors depend on various factors, ranging from local temperature to regional energy policies. For instance, residents in Florida are less likely to consume more energy in space heating than those from Minnesota. The research found that with the same number of occupants and occupancy periods, electricity consumption still changes at a great level due to the variation of occupant behaviors.

5.5 Methodologies of residential energy use modeling.

Complexity of residential energy use patterns and dependence on data input level make modeling residential energy use potentially challenging. However, based on the different capabilities, strengths, weaknesses, and applicability of each modeling technique, matching input data with models that can best use them could produce satisfactory models. Generally speaking, techniques employed to model residential energy use can be classified into two categories, “top-down” and “bottom-up”, and this terminology is referred to the hierarchal position of data inputs (Swan and Ugursal 2009)**[97**], as indicated in Figure 5.2.

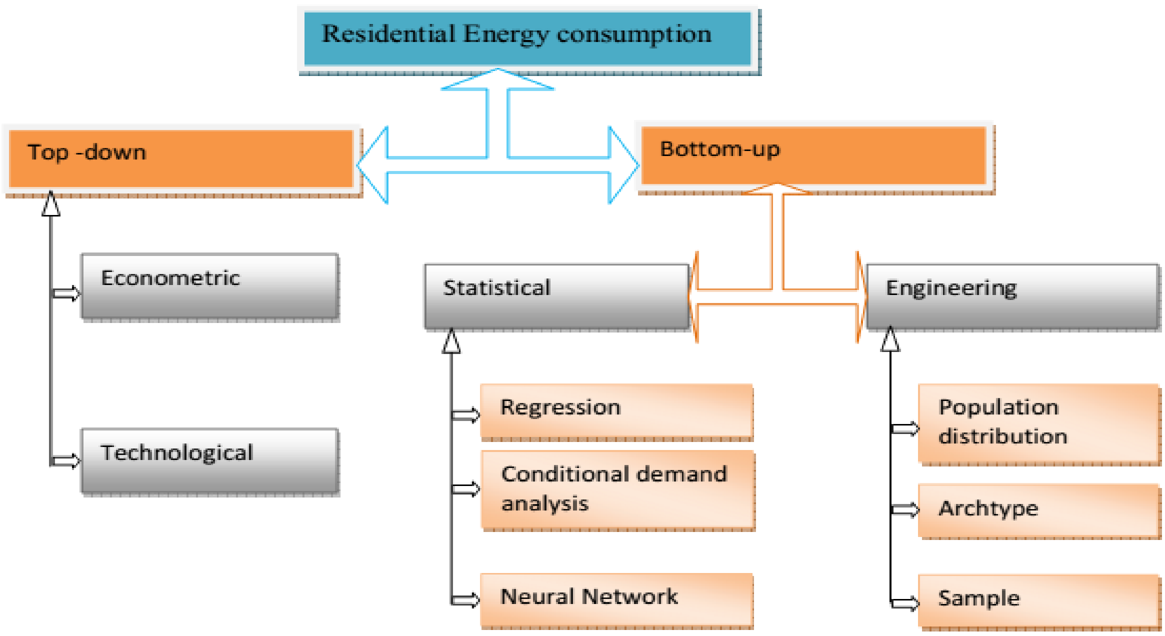

Figure 5.2. Modeling techniques for estimating the regional and national residential energy consumption.

5.6 Top-down approach.

This approach evaluates the residential energy sector with a special emphasis on the effects long-terms of changes, that is, rather than focusing on the effects from individual energy consumption, it suggests considering the residential sector as an energy sink, and using estimates of total residential sector energy construction conditions, and demolition rate in the residential sector, to attribute the energy consumption to characteristics in the whole residential sector. For example, if demolition rate increases by 5%, a top-down model may estimate that the residential sector could consume 2% less energy, due to a decreased number of occupants.

One primary advantage of top-down model is the data accessibility. As mentioned above, it employs many commonly used variables, many of which are of great availability and are from historical dataset. But, the reliance on historical dataset is also a disadvantage of top-down model, because of its incapability to model discontinuous technology advances that could significantly influence a variable by a technology breakthrough. Additionally, omitted information on individual energy end uses further keeps top-down model from reducing the energy consumption, due to its incapability of identifying key sectors of potential energy efficiency improvements (Swan and Ugursal 2009)[**97**] as well as macro-variables, such as macroeconomic indicators, and climatic variations.

The top-down modeling start from the level of aggregates, its target aims to fit in a historical time series of energy consumption and CO2 emissions data at national level. This type of models tends to be used to study the correlation and the inter-relationship between the energy sector and economic development, and could be considered as econometric and technological top-down models. These models are mainly based on the relationship between energy consumption and variables such as income, energy prices, gross domestic product to explain the interconnections between the energy sector and the economic output. It may include general climatic conditions, such as population-weighted temperature. The top-down models usually lack information about details on current and future technological options. They put more emphasis on relationship observed in the past and the macroeconomic trends, rather than on the individual physical factors in buildings that can influence energy demand [**98**]. More important, the dependence on past energy–economy interactions might also not be appropriate when dealing with climate change issues where environmental, social, and economic conditions might be entirely different to those previously experienced. They have no inherent capability to model discontinuouschanges in technology. The technological top-down models include a range of other factors that influence energy use (i.e. saturation effects, technological progress, and structural change), however they are not described explicitly within the models [**99**].

The top-down approach treats the residential sector as an energy sink and does not distinguish energy consumption due to individual end-uses. Top-down models determine the effect on energy consumption due to ongoing long-term changes or transitions within the residential sector, primarily for the purpose of determining supply requirements. Variables which are commonly used by top-down models include macroeconomic indicators (gross domestic product (GDP), employment rates, and price indices), climatic conditions, housing construction/demolition rates, and estimates of appliance ownership and number of units in the residential sector. Econometric models are based primarily on price (of, for example, energy and appliances) and income. Technological models attribute the energy consumption to broad characteristics of the entire housing stock such as appliance ownership trends. In addition there are models which utilize techniques from both groups.

Top-down models operate on an equilibrium framework which balances the historical energy consumption with that estimated based on input variables. The strengths of top-down modeling are the need for only aggregate data which are widely available, simplicity, and reliance on historic residential sector energy values which provide‘‘inertia’’ to the model. As the housing sector rarely undergoes paradigm shifts(e.g. electrification and energy shocks), a weighted model provides good prediction capability for small deviations from the status quo. For example, if housing construction increased the number of units by 2%, an increase in total residential energy consumption of 1.5% might be estimated by the top-down model, as new houses are likely more energy efficient. If this construction was increased to 10% of the units the top-down model could have difficulty in producing an appropriate estimate as the vintage distribution of the housing stock would have changed significantly. The reliance on historical data is also a drawback as top-down models have no inherent capability to model discontinuous advances in technology. Furthermore, the lack of detail regarding the energy consumption of individual end-uses eliminates the capability of identifying key areas for improvements for the reduction of energy consumption.

As an example of a simple top-down model, the annual delivered energy price and temperature (ADEPT) was recently developed for annual household energy consumption in the UK since1970 [**100**]. This is a regression model based on average heating season temperature and an inflation adjusted energy price. The aim of the ADEPT model is just to allow yearly consumption data to be compared with what might be expected after allowing for the prevailing temperature and price settings. It provides policymakers and the public a straightforward way of determining if changes are outside that expected from these basic drivers(and as might be anticipated to occur from major changes in the energy performance of the stock). So while the model acts to prevent any reductions in national energy consumption that are associated with warmer conditions or price changes from being automatically ascribed to fundamental improvements in the sector, it is not intended to explain consumption in more detail, such as quantifying the role of other factors and the effectiveness of specific policy measures.

5.7 Bottom-up approach.

The bottom-up approach encompasses all models which use input data from a hierarchal level less than that of the sector as a whole. Models can account for the energy consumption of individual end-uses, individual houses, or groups of houses and are then extrapolated to represent the region or nation based on the representative weight of the modeled sample. The variety of data inputs results in the groups and sub-groups of the bottom-up approach as shown in Fig. 5.2

Bottom-up methods are built up from data on a hierarchy of disaggregated components, that are then combined according to some estimate for their individual impact on energy usage, for instance in the UK the contribution from Victorian terrace housing might be weighted according to their prevalence in the stock. This implies that they may be useful for estimating how various individual energy efficiency measures impact on CO2 emission reduction, such as by replacing one type of heating systems with another. Often these models are seen as a way to identify the most costeffective options to achieve given carbon reduction targets based on the best available technologies and processes [**101**].

The bottom-up models work at a disaggregated level, and thus need extensive databases of empirical data to support the description of each component [**102**]. Contingent upon the type of data input and structure, statistical and building physics based methods represent two distinct approaches applied in the bottom-up models to determine the energy consumption of specified end-uses [**97**].

5.8 Approach based on building physics.

Building physics based modelling techniques generally include the consideration of a sample of houses representative of the national housing stock and utilization of a building energy calculation method to estimate the delivered energy consumption [**103**]. Therefore, they require data input composed of quantitative data on physically measurable variables such as the efficiency of space heating systems and their characteristics, information on the areas of the different dwelling elements (walls, roof, floor, windows, doors) along with their thermal characteristics (U-values), internal temperatures and heating patterns, ventilation rates, energy consumption of appliances, number of occupants, external temperatures, etc. [**99**]. The combination of building physics and empirical data from housing surveys and other data sets, as well as assumptions about buildings operation, give modellers the means to estimate energy consumption in dwellings for the past, present, and future. By developing different scenarios, the bottom-up models appear to have the potential to be used to assess the impact of specific carbon reduction measures on the overall demand , which can energy be used as part of an evidence based approach to medium to longterm energy supply strategy. In Europe, bottom-up building physics stock models are seen as useful tools to provide for policymakers with estimates for the effectiveness of policies and can help to identify technological measures that end-use efficiencies. A level of building physics stock model's complexity is determined by their core calculation engines. In the UK, for example, the most widely used physically based model for the calculation of domestic energy demand is BREDEM (The Building Research Establishment's Domestic Energy Model) [**104-107**]. It consists of a series of heat balance equations and empirical relationships to produce an estimate of the annual (BREDEM-12 [**105**]) or monthly (BREDEM-8 [**106-107**]) energy consumption of an individual dwelling. Importantly, an annual modified version of BREDEM (BREDEM-9) forms the basis of the UK Government's Standard Assessment Procedure (SAP [**108**]) which is used for the energy rating of dwellings. One of the main advantages of the BREDEM algorithms for model developers is their overall modular structure so that they can be easily modified to suit particular needs. For instance, BREDEM determines the electricity use for lights and appliances using simple relationships based on floor area and occupant numbers, which can easily be replaced by a more sophisticated approach if needed.

5.9 Approach based on statistics:

Statistical methods (SM) rely on historical information and types of regression analysis which are used to attribute dwelling energy consumption to particular end-uses. Once the relationships between end-uses and energy consumption have been established, the model can be used to estimate the energy consumption of dwellings representative of the residential stock. Engineering methods (EM) explicitly account for the energy consumption of end-uses based on power ratings and use of equipment andsystems and/or heat transfer and thermodynamic relationships. Common input data to bottom-up models include dwelling properties such as geometry, envelope fabric, equipment and appliances, climate properties, as well as indoor temperatures, occupancy schedules and equipment use. This high level of detail is strength of bottom-up modeling and gives it the ability to model technological options. Bottom-up models have the capability of determining the energy consumption of each end-use and in doing so can identify areas for improvement. As energy consumption is calculated, the bottom-up approach has the capability of determining the total energy consumption on the residential sector without relying on historical data.

The primary drawback caused by this level of detail is that the input data requirement is greater than that of top-down models and the calculation orsimulation techniques of the bottom-up models can be complex. In all cases the bottom-up models must be extrapolated to represent the housing sector. This is accomplished using a weighting for each modeled house or group of houses based on its representation of the sector.

A notable capability of the bottom-up approach is its ability to explicitly address the effect of occupant behaviour and ‘‘free-energy’’ gains such as passive solar gains. Although free energy gains have historically been neglected during residential analysis, they are now a common design point as focus is placed on alternative energy technologies. Statistical methods attribute all of the measured energy consumption to end-uses and in doing so incorporate the occupant’s behaviour with regards to use andsettings of appliances. However, if all energy sources are not accounted for, the end-use energy consumption estimates are derated by this consumption difference. Based in its physical principle roots, the EM has the ability to capture the additional energy consumption level based on requirements, inclusive of free energy. However, occupant behaviour must be estimated which is difficult as behaviour has been shown to vary widelyand in unpredictable ways.

The following sections examine the modeling techniques by reviewing published models. The applicability, basic methodology and major conclusions found by the researchers are listed. There is a tendency towards chronological order to facilitate understanding of the modeling technique development stream and contributions by the authors. Certain techniques were found to follow a clear development stream(e.g. conditional demand analysis) while others contain a wide variety of techniques and are discontinuous. Emphasis is placed on modeling technique development and lesson the simple application to a new region.

5.10 Top-down models.

The use and development of the top-down modeling approach proliferated with the energy crisis of the late 1970s. In an effort to understand consumer behaviour with changing supply and pricing, broad econometric models were developed for national energy planning. These models require little detail of the actual consumption processes. The models treat the residential sector as an energy sink and regress or apply factors that affect consumption to determine trends. Most top-down models rely on similarstatistical data and economic theory. As the housing stock in most regions is continuously undergoing improvement and increase, simply modeling the energy consumption solely as a function of economic variables is short termed. Hirst et al. [**109**] initiated an annual housing energy model of the USA. Their model relied on econometric variables and included a component for growth/contraction of the housing stock. Their work was expanded and improved over the following years resulting in an econometric model which had both housing and technology components [**110-111**].

The housing component evaluates the number of houses based on census data, housing attrition and new construction. The technology component increases or decreases the energy intensiveness of the appliances as a function of capital cost. The economic component evaluates changes in consumption based on expected behavioural changes and efficiency upgrades made to the technology component. Finally, market penetration is considered a function of income and demand/supply. The simulation model combines the changes in outputs of the components and estimates the energy consumption given historic energy consumption values. The authors felt their model was sensitive to major demographic, economic and technological factors, but recognized the need to continually update all assumed information to improve quality. Saha and Stephenson [**112**] developed a similar model for New Zealand although it had a technological focus.

Their economic and housing components drive separate analysis of SH, DHW, and cooking, and are added to obtain total consumption. Their basic energy balance, as shown in Eq. (1), determines the annual energy consumption of each fuel used to support each end-use group as a function of stock, ownership, appliance ratings and use. Using historicaldata, their prediction capability was excellent throughout the 1960s and 1970s although there is significant divergence toward the latter half of the 1970s. This may be due to the model not accounting for shifts in home insulation levels

$$E_{an,e,f} = SC_{e,f} R_{e,f} U_{e,f} \tag{5.1}$$

where *E* is the annual energy consumption of end-use group e, corresponding to fuel type, f, S is the level of applicable housing stock, *C* is the appliance ownership level, *R* is the rating of all appliances within an end-use group, and *U* is a use factor.

Haas and Schipper [**19**] recognized that energy consumption of the housing stock is poorly modeled by only a few econometric indicators. They identified ‘‘irreversible improvements in technical efficiency’’ which are a result of consumer response that not only reduces energy consumption due to rising price, but responds by makingupgrades to their dwelling. Consequently a subsequent reduction in price would not cause a perfectly elastic rebound. To quantify this asymmetrical elasticity, they developed econometric models for the USA, Japan, Sweden, West Germany and the UKbased on the time periods of: 1970–1993, 1970–1982, and 1982–1983. They found very flat (nearly zero) rebound of energy consumption after periods of increased price, suggesting the typical price elasticity is a diluted average. They also state saturation of appliances can lead to reduced income elasticity and they found limited correlation between increasing technological efficiency leading to increased energy use. When the authors included technological energy intensity in their model (using a bottom upapproach based on individual appliance ratings) they found reduced error and that the irreversible share of price elasticity became hidden in the coefficient of intensity.

Two tier econometric models that evaluate choice of system (discrete) and utilization (continuous) are common. Nesbakken [**113**] developed such a model for Norway, testing sensitivity and stability across a range of income and pricing. The author considered three years of expenditure surveys and energy consumption to determine differences along the time dimension. Their findings were consistent with negative price elasticity and maximization of utility. Different income groups resulted in similar findings although the responses were slightly higher for higher income groups. Bentzen and Engsted [**114**] revived simple economic modeling of residential energy consumption. They tested the following three annual energy consumption regression models for Denmark:

$$E_{an,t} = b + c_1 E_{an,t-1} + c_2 I_{disp,t} + c_3 Pc_t \tag{5.2}$$

$$E_{an,t} = b + c_1 E_{an,t-1} + c_2 I_{disp,t} + c_3 Pc_t + c_4 HDD_t \tag{5.3}$$

$$E_{an,t} = b + c_1 E_{an,t-1} + c_2 I_{disp,t} + c_3 Pc_t + c_4 HDD_t + c_5 P_{ct-1} \tag{5.4}$$

where E is the annual energy consumption for year t, I is the disposable household income, Pc is the price of energy, HDD is the heating degree days, b is a constant, and c are coefficients. From 36 years of data they found that, in all three cases, longterm energy consumption was strongly affected by income and lagged energy consumption, and lagged pricing trumped current pricing. Their findings indicate that future energy price must increase with income to maintain the current consumption level.

Using aggregate national residential energy values, Zhang [**103**] compared international values of unit energy consumption (UEC) to determine to potential changes in the sector's energy consumption. The author calculated the UEC for various regions of China based on energy consumption and the number of residences, and compared the Chinese UEC with those of other countries. The results indicate that when normalized for heating requirements based on climate (i.e. heating degree days (HDD)),

Japan uses approximately half the UEC of the USA and Canada, as shown in Fig. 3. This may be attributed in part to the high ratio of apartment buildings in Japan (40%). China is closer to one quarter of the North American UEC, owing to limited adoption of space heating devices. The paper also discusses the potential of the Chinese residential sector following the North American or Japanese energy consumption characteristics. Interestingly, the model identified that although China is growing, the secondary energy consumption of the residential sector has remained constant due to switching away from coal as a fuel.

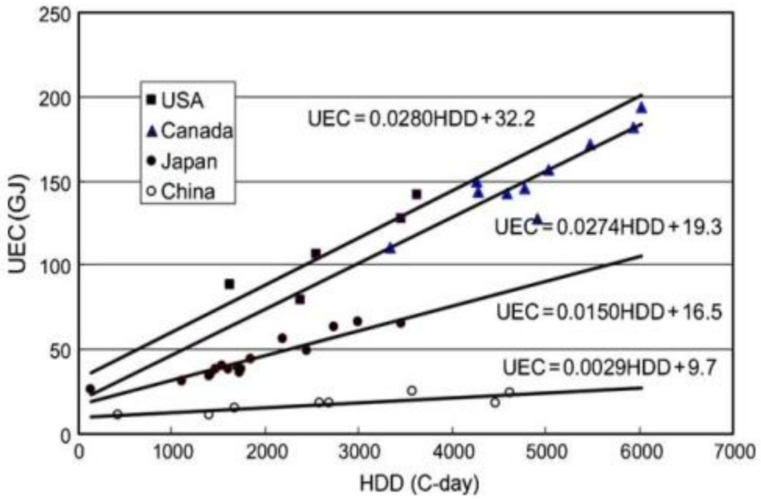

Figure 5.3 Comaprison of National UEC values (103)

5.11 Bottom-up models.

The bottom-up approach was developed to identify the contribution of each end-use towards the aggregate energy consumption value of the residential stock. This refines the understanding of the details associated with the energy consumption. There are two distinct categories used in the bottom-up approach to evaluate the energy consumption of particular enduses. The SM utilizes dwelling energy consumption values from a sample of houses and one of a variety of techniques to regress the relationships between the end-uses and the energy consumption. SM models can utilize macroeconomic, energy price and income, and other regional or national indicators, thereby gaining the strengths of the top-down approach. The EM relies on information of the dwelling characteristics and end-uses themselves to calculate the energy consumption based on power ratings and use characteristics and/or heat transfer and thermodynamic principles. Consequently, the engineering technique has strengths such as the ability to model new technologies based solely on their traits. Once developed, the bottom-up models may be used to estimate the energy consumption of houses representative of the residential stock and then these results can be extrapolated to be representative of the regional or national residential sector.

5.12 Statistical techniques.

The vast quantity of customer energy billing information stored at the major energy suppliers worldwide is an unprecedented data source for energy modeling. Researchers have applied a variety of SM techniques to utilize this and other information to regress the energy consumption as a function of house characteristics. A capability of the SM techniques is their ability to discern the effect of occupant behaviour. This is of benefit to residential modeling as occupant behaviour has been found to range widely and is poorly represented by simplified estimates. The three well-documented techniques, all of which use a sample of houses, are:

5.13 Regression

The regression technique uses regression analysis to determine the coefficients of the model corresponding to the input parameters. These models regress the aggregate dwelling energy consumption on to parameters or combinations of parameters which are expected to affect energy consumption. The model is evaluated based on goodness of fit. Input variables which are determined to have a negligible effect are removed for simplicity. Based on the combinations of inputs, the model's coefficients may or may not have physical significance. Chao Li [home energy consumption estimation by end use and energy efficiency upgrade recommendations- Master Project Duke university 2014] constructed 4multi-regression models for each home energy end-use, water heating, space heating, space cooling, and appliances, choosing by independent variables from (Residential Energy Consumption Survey) RECS dataset and taking each end use category as dependent variable. Specifically, combined with associated independent variables such as housing unit features (e.g. number of rooms, square feet), householder's characteristics (e.g. income, race), and regional influences (e.g. heating degree days), ordinary least square (OLS) is employed to build the multi-regression model. Generally, each established model can be formulated as:

$$\ln C_m = A_m + \sum_n B_{m,n} R_{m,n} \tag{5.5}$$

where C_m indicates the total annual energy consumption of category *m*, per household, A_m indicates the constant value for establishement regression model of end use category *m*, R_{mn} indicates the chosen variable *n* form from RECS, accounting for end use category *m*, B_{mn} indicates the coefficient of variable R_{mn}. The reason that those regression models were constructed as log-linear type, as shown in formula (5), is the relatively higher adjusted R-squared value**.** An excel-based model is also built to provide individual user an approach to get more accurate end-use estimates by inputting individual information for each variable. Specifically, each end use estimate is calculated through the following equation:

$$E_m = e^{Am} + \sum_n (B_{mn}.I_{mn}) \tag{5.6}$$

Where E_m indicates the estimated total annual energy consumption of category *m*, per household; $A_m$indicates the constant value for established regression model of end use category m ; I_{mn} indicates the variable chosen variable n from RECS for each enduse model, whose value comes from individual input; B_{mn} indicates the coefficient of variable I_{mn}. In an effort to identify unusual metering occurrences (e.g. broken meter) and evaluate the level of households with more than one energy source for space heating, Hirst et al. [**109-110**] used the Princeton scorekeeping model with monthly or bimonthly energy supplier billing data. They examined the weather and non-weather sensitive elements of the household energy consumption of dwellings by regressing the energy billing data onto a nonweather dependent constant and a weather dependent coefficient based on HDD, as shown in Eq. (7). They left the reference temperature for determination of the HDD as a variable, to be adjusted between 4 8C and 24 8C in an effort to reduce error and increase the multiple correlation coefficient (R2). The adjustment of Tref was shown to be effective by Jones and Harp [**115**] who reduced it from the accepted value of 18.0–16.9 8C and achieved more representative results for the space heating requirements of Oklahoma.

$$E_{an,t} = b + cHDD_t(T_{ref}) \qquad (5.7)$$

where E is the annual energy billing data from period, t, HDD is the heating degree days with reference temperature, T_{ref}, b is constant, and c is a coefficient. The coefficients in the above model were termed ‘‘fingerprints’’and directed towards determining unusual metering occurrences and identifying the use of alternative space heating fuelswhen comparing the monthly measured house energy consumption to that predicted by the model. Recently, a similar analysis was conducted by Raffio et al. [**116**] with the goal of identifying energy conservation potential within a regional area. A similar model with ‘‘energy signature’’ coefficients was developed. These coefficients were compared regionally and also evaluated over the course of the seasons for the identification of patterns which can be used to assess potential energy conserving changes. The authors give examples such as the application of DHW conserving devices to dwellings with high non-weather dependent energy consumption and the application of programmable thermostats to high balance point T_{ref} buildings. While the model cannot determine the impact of these changes, it may identify the potential for application. The primary advantages of this model are simplicity, only requiring billing data, and the capability of normalized comparison across many different residences using a sliding scale which iscontinuously updated from new billing data. Utilizing larger sets of billing data, the models can become descriptive of a nation. Tonn and White [**117**] developed a regression model with four simultaneous equations: separate equations of electricity use associated with SH and AL, wood use, and indoor temperature. Data was sourced from 100 sub-metered homes that utilized wood heat. In an attempt to encompass

occupant behaviour they conducted an extensive survey (300 questions) which asked questions related to goals and motivations, and occupants selfdefined socioeconomic response. Their desire was to determine the motivation or ethical considerations in energy use. They developed 30 different regression models, consecutively eliminating variables with insignificant
impact. Their four regression equations achieved R2 values ranging from 0.80 to 0.91. While housing characteristics played a distinct role in the models, they found ethical motivations outweigh economic motivations. They found education level and age of the head of household not to affect any of the four equations. Douthitt [**118**] constructed a model of residential space heating fuel use in Canada by regressing consumption as a function of present and historic fuel price, substitute fuel price, total fuel consumption, and a vector of building structure, climatic, and occupant characteristics. Using 370 records, they achieved R2 values equal to 0.52 (natural gas), 0.76 (heating oil), 0.37(electricity with natural gas available), and 0.79 (electricity with no natural gas available). The author found that the sample with energy source alternatives achieve near unity price elasticity, the implication being towards fuel subsidies being ineffective at reducing annual fuel cost per house. Income elasticity was also very unitary, indicating that providing subsidies (in effect income) to low-income families would result in increased usage. Fung et al. [**118**] adopted the regression techniques of [**119**] andothers to determine the impact on Canadian residential energy consumption due to energy price, demographics, and weather and equipment characteristics. They found both short and long term fuel price elasticity to be negative, although the long term was.

5.14 Conditional demand analysis (CDA)

The CDA method performs regression based on the presence of end-use appliances. By regressing total dwelling energy consumption onto the list of owned appliances which are indicated as a binary or count variable, the determined coefficients represent the use level and rating. The primary strength of this technique is the ease of obtaining the required input information: a simple appliance survey from the occupant and energy billing data from the energy supplier. However, it does require a dataset with a variety of appliance ownership throughout the sample. This technique exploits the differences in ownership to determine each appliance's component of the total dwelling energy consumption. In order for the CDA technique to produce reliable results, and depending on the number of variables used, data from hundreds or even thousands of dwellings are required.

They proposed a conditional demand regression equation based on the indication of appliance ownership and expected relations with other house characteristics such as floor area or demographic factors gathered from a survey. Their regression equation, one for each month of a year of billing data, take the form:

$$E_{mo} = \sum_{i} \sum_{app} c_{app,j}(V_i C_{app}) \tag{5.8}$$

where E is the monthly electrical energy consumption, C is a variable indicating appliance presence or count for appliances, *app*, V is a set of interaction variables with elements, i, such as the number of occupants, income, and floor area, and c is a coefficient. The appliance at $app = 0$ is unspecified to account for appliances whose presence were not explicitly surveyed and the interaction variable when $i = 0$ accounts for appliance energy consumption unrelated to interactions with other surveyed information.

5.15 Neural network (NN)

The NN technique utilizes a simplified mathematical model based on the densely interconnected parallel structure of biological neural networks. The technique allows all end-uses to affect one another through a series of parallel ‘‘neurons’’. Each neuronhas a bias term and array of coefficients that are multiplied by the value of the preceding layer's neurons. Similar to regression models it seeks to minimize error and may apply scaling and activation functions to account for non-linearity. As it is a parallel model, the coefficients have no physical significance.

5.16 Artificial Neural Network (ANN).

An Artificial Neural Network is an information processing paradigm which attempts to simulate the functionality of the human brain and model non-linear systems. This study will mainly use a forward neural network model and select the second layer BP network model, which includes the input layer, a hidden layer and the output layer. The errors of the output from a BP network are back propagated by means of the same connections used in the feed-forward mechanism by the derivation of the feed-forward transfer function. It has higher performance and greater value in use than the traditional macro model method [**25,84**]. This paper selects the standard BP learning and training functions with the standard BP algorithm. The process of a single hidden layer BP network algorithm with converse error propagation is as follows [**109**]:

When a sample NO.*p* in the sample set is read, the operating characteristic of the NO.*j* neuron in NO.*l* layer network is:

$$\begin{aligned} net_{jp}^{l} &= \sum_{i=1}^{l-1} w_{ji}^{(l)} o_{ip}^{i=1} - \theta_j^i \\ o_{jp}^{l-1} &= f(net_{jp}^{\ l}) \end{aligned} \tag{5.9}$$

where: *wji* is the connection threshold from neuron *I* to neuron *J*; *nl*-1 is the number of nodes in layer *l* -1:

$$f_l(x) = \frac{1}{1+e^{-x}} \tag{5.10}$$

For the output layer:

$$O_{jp}^{L} = f_L(net_{jp}^{L}) = \sum_{i=1}^{n_{L-1}} W_{ji}^{(L)} O_{ji}^{(L-1)} - \theta_j^{L} \tag{5.11}$$

Learning neural network aims to achieve *Ep* of each sample minimum, thus ensuring the total error of the grid:

$$E_p = \frac{1}{2}\sum_{j=1}^{m}(Y_j - \hat{Y}_{jp})^2 \ \ (p=1,2,\ldots,P) \tag{5.12}$$

where, *m* is the number of output nodes (in this case these are living energy consumption of residential buildings, total energy consumption, total number of persons, gross domestic product, disposable income of urban residents, *etc.*). Y_j *Yjp* , are theexpected output and the actual output of NO.*j* node in the output layer. The gradient descent method can be used to find the changes of weighted value and error propagation and gradient algorithm to correct weighted value of network and threshold. Then we get the iterative equation of the weighted value in NO.*l* layer:

$$\begin{aligned} &W(k+1) = W(k) + W(k+1) \\ &W = \{w_{ij}\} \end{aligned} \tag{5.13}$$

Where, *k* is the number of iterations , and the order $w\ ji = \eta\delta pjO_{ip}^{(i\text{-}1)}$, where η is learning efficiency (value η = 0.01 - 0.8). The training sample set selects the sample which is similar to the forecasting energy consumption to train the artificial neural network forecasting system through two principles: near time and matching input. This is because it has several advantages as follows [**90**]:

1. The training samples which are continuously changing keep up with changes of the energy consumption characteristics as possible.

2. Using similar samples for training can ensure the accuracy of prediction;3. The training time is saved by filtering the sample.

5.17 Mathematical model of electricity energy consumption.

The energy use can be adequately described by mathematical models that relate theconsumption to any factors that affect it. The model of linear regression is of the following form.

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_n + e \quad (5.14)$$

where Y is the dependent variable , x_n (n=1,2,….): independent variables, β_n(n=1,2,….) regression coefficients,$\beta_0$regression intercept, e: residual error

The Least Squares Method is used to develop values bn estimates of the model parameters n which gives us the estimated regression model:

$$y = b_0 + b_1 x_1 + b_2 x_2 + ... + b_n x_n \quad (5.15)$$

This model can be used to estimate the value of y. We only need a set of x values. In our case, the model will help us to estimate the future energy use or the energy consumption after the retrofit This model depicts the energy consumption by including the base load β_0 that is independent of the outside temperature (independent variable x). When the temperature exceedsβ_2,the consumption becomes dependent on the independent variable and varies linearly with it. The coefficient that describes this correlation is β_1.Using regression correlates energy use to other variables. The regression coefficients represent the physical relationship existing between the electrical consumption for instance and could be used to evaluate the energy saving opportunities.

The formulated mathematical model is based on mass and energy balances and the equations (1) to (23) describe the complete model. The subscripts b, w, f, r and fur denote building unit, walls, floor, roof and furniture respectively. The nomenclature is presented in

Table 5.2.The nomenclature for the model

Symbol	Units	Description
A_j	m^2	Area of jth element
$A_{i,j}$	m^2	Area of the surface between ith and i+1th layer of jth element
$c_{p,b}$	$\frac{J}{kg.K}$	Specific heat capacity of moist air inside the building unit
$c_{p_{i,j}}$	$\frac{J}{kg.K}$	Specific heat capacity of ith layer of jth element
$\dot{E}_x$	W	Total energy flow rate to the x direction
$\dot{H}_x$	W	Enthalpy flow rate to the x direction
h_x	$\frac{J}{kg}$	Specific enthalpy of incoming air to the x direction
$h_{b,j}$	$\frac{W}{m^2K}$	Convection heat transfer coefficient of jth element inside the building unit
$h_{\infty,j}$	$\frac{W}{m^2K}$	Convection heat transfer coefficient of jth element outside the building unit
$K_{i,j}$	$\frac{W}{m.K}$	Thermal conductivity of the ith layer of jth element
$l_{i,j}$	m	Half thickness of the ith layer of jth element
M_b	$\frac{kg}{mol}$	Average molar mass of moist air in the building unit
m_b	kg	Mass of air water mixture in the building unit
$(P\dot{V})_x$	W	Pressure work to the x direction
$\dot{Q}_j$	W	Heat gain or loss due to jth element
$\dot{q}_{i,j}$	W	Heat generation in the ith layer of jth element
R	$\frac{Pa.m^3}{mol.K}$	Gas constant
r	m	Radius of a sphere
$\delta r_{i,fur}$	m	Half thickness of ith layer in a spherical furniture
T_∞	K	Outside temperature
T_b	K	Temperature of air in the building unit
T_{centre}	K	Temperature at the centre of the assumed furniture sphere
$T_{i,j}$	K	Temperature of the i^{th} layer of element j
$T^s_{i,j}$	K	Temperature of the surface between $(i-1)^{th}$ and i^{th} layer of element j
t	s	Time
U_j	$\frac{W}{m^2K}$	Overall heat transfer coefficient of jth element
ρ_{in}	$\frac{kg}{m^3}$	Density of moist air flowing into the building unit
$\rho_{i,j}$	$\frac{kg}{m^3}$	Density of ith layer of jth element
$\alpha_{i,j}$	$\frac{m^2}{s}$	Thermal diffusivity of ith layer of jth element
ϵ	-	Emissivity of the surface
σ	$\frac{W}{m^2K^4}$	Stefan-Boltzmann constant

$$\frac{dE_b}{dt} = \dot{E}_{in} - \dot{E}_{out} + \dot{Q} + \dot{W} \tag{5.16}$$

$$\frac{dE_b}{dt} = \dot{E}_{in} - \dot{E}_{out} + \dot{Q} + \dot{W} \tag{5.17}$$

$$E_b = U_b^E = H_b - P_b V_b \tag{5.18}$$

$$\dot{W} = (P\dot{V})_{in} - (P\dot{V})_{out}$$

(5.19)

$$\frac{dT_b}{dt} = \frac{\dot{V}_{in}\rho_{in}h_{in} - \dot{V}_{out}\rho_b h_{out} + \dot{Q}}{V_b\rho_b(c_{p,b} - \frac{R}{M_b})} - \frac{T_b}{\rho_b}\frac{d\rho_b}{dt} \tag{5.20}$$

$$\dot{Q}_{Supply} = \dot{Q}_{Heater} + \dot{Q}_{People} + \dot{Q}_{Appliances} + \dot{Q}_{Solar} \tag{5.21}$$

$$\frac{dT_{i,w}}{dt} = \alpha_{i,w}\frac{T_{i+1,w}^8 - 2T_{i,w} + T_{i,w}^8}{l_{i,w}^2} \tag{5.22}$$

$$h_{b,w}(T_b - T_{i,w}^8) = -\frac{K_{1,w}}{2l_{1,w}}(T_{2,w}^8 - T_{1,w}^8) \tag{5.23}$$

$$\frac{-K_{i,w}A_{i+1,w}}{2l_{i,w}}(T_{i+1,w}^8 - T_{i,w}^8) = h_{\infty,w}A_{i+1,w}(T_{i+1,w}^8 - T_\infty) + \sigma\varepsilon_{i+1}(T_{i+1,w}^8 - T_\infty^4) \tag{5.24}$$

$$\frac{dT_{i,f}}{dt} = \alpha_{i,f}\frac{T_{i+1,f}^8 - 2T_{i,f} + T_{i,f}^8}{l_{i,f}^2} + \frac{q_{i,f}}{\rho_{i,f}c_{p_{i,f}}} \tag{5.25}$$

$$h_{b,f}(T_b - T_{i,f}^8) = \frac{-K_{1,f}}{2l_{1,f}}(T_{2,f}^8 - T_{1,f}^8) \tag{5.26}$$

$$\frac{dT_{i,r}}{dt} = \alpha_{i,r}\frac{T_{i+i,r}^8 - 2T_{i,r} + T_{i,r}^8}{l_{i,r}^2} \tag{5.27}$$

$$h_{b,r}(T_b - T_{i,r}^8) = \frac{-K_{1,r}}{2l_{1,r}}(T_{2,r}^8 - T_{1,r}^8) \tag{5.28}$$

$$\frac{-K_{i,r}A_{i+1,r}}{2l_{i,r}}(T_{i+1,r}^8 - T_{i,r}^8) = h_{\infty,r}A_{i+1,r}(T_{i+1,r}^8 - T_\infty) + \sigma\varepsilon_{i+1}(T_{i+1,r}^8 - T_\infty^4) \tag{5.29}$$

$$\frac{dT_{i,fur}}{dt} = \alpha_{i,fur}(\frac{T_{i+i,fur}^8 - 2T_{i,fur} + T_{i,fur}^8}{\delta r_{i,fur}^2}) + \alpha_{i,fur}(\frac{1}{r}\frac{T_{i+i,fur}^8 - T_{i,fur}^8}{\delta r_{i,fur}}) \tag{5.30}$$

$$h_{b,fur}(T_b - T_{i,fur}^8) = \frac{-K_{1,fur}}{2l_{1,fur}}(T_{2,fur}^8 - T_{1,fur}^8) \tag{5.31}$$

$$\dot{Q}_{window} = U_{window} A_{window} (T_b - T_\infty) \quad (5.32)$$

$$\dot{Q}_{door} = U_{door} A_{door} (T_b - T_\infty) \quad (5.33)$$

$$\dot{Q}_{walls} = U_{walls} A_{walls} (T_b - T_\infty) \quad (5.34)$$

$$\dot{Q}_{floor} = h_{b,fur} A_{fur} (T_b - T_{center}) \quad (5.35)$$

$$\dot{Q}_{roof} = U_{roof} A_{roof} (T_b - T_\infty) \quad (5.36)$$

$$\dot{Q}_{fur} = h_{fur} A_{floor} (T_b - T_\infty) \quad (5.37)$$

$$T_{in} = \frac{\eta \dot{V}_{out} \rho_b c_{p,b} (T_b - T_\infty)}{\dot{V}_{in} \rho_b c_{p,in}} + T_\infty \quad (5.38)$$

5.18 Discussion

a- Critical analysis of top-down and bottom-up approaches

The top-down and bottom-up approaches each have distinct similarities and differences, as well as advantages and disadvantages. Two of the most critical issues that characterize these approaches are the required input information and the desired range of modeled scenarios. **Strengths and weaknesses of the top-down approach**Top-down approaches are relatively easy to develop based on the limited information provided by macroeconomic indicators such as price and income, technology development pace, and climate. Top-down models heavily weigh the historical energy consumption which is indicative of the expected pace of change with regards to energy consumption. Models that evaluate from a regional or national scope are useful for estimating the required energy supply and the implications of a changing economy. Contrary to other studies and with respect to a practical sense given today's energy environment, Haas and Schipper [**19**] clearly identified non-elastic response due to ''irreversible improvements in technical efficiency''. This exemplifies the importance of including a representative technological component in top-down models. Jaccard and Bailie [**122**] discussed the notable dichotomy that top-down models estimate high abatement costs for reducing carbon dioxide emissions whereas bottom-up models' estimates are notably lower. They attribute this to economists' over-reliance on the autonomous energy efficiency index (AEEI) and the elasticity of substitution (ESUB). The NEMS has included both a technology and distributed generation component [**105**]. This indicates that top-down modeling systems are now attempting to account for the uptake of new technologies. While these techniques may account for future technology penetration based on historic rates of change, they do not provide an indication of the potential impacts of such technologies and are therefore not helpful in the development of policy or incentive to encourage them.**Strengths and weaknesses of the bottom-up approach** Bottom-up statistical techniques bridge the gap between detailed bottom-up end-use energy consumption models and regional or national econometric indicators. These techniques are capable of encompassing the affects of regional or national economic changes while indicating the energy intensity of particular end-uses. The primary information source of the bottom-up SM is energy supplier billing data. While this is private information, the sheer quantity and quality of this information warrants further compilation and use. By disaggregating measured energy consumption among end-uses, occupant behaviour can be accounted for. This is a distinct advantage of the SM over the EM. Of the three bottom-up SM techniques, common regression is the least favored as the utilized inputs vary widely among models, limiting their comparison. In contrast, CDA is focused on simplifications of enduses and is therefore easily ported to other locations and its predictions are comparable among different studies. As appliances currently on the market vary widely in size and less in technology, the addition of such information could be beneficial for future CDA studies. Although the NN technique allows for the most variation and integration between end-uses, resulting in the highest prediction capabilities (Aydinalp et al. [**123**]), its coefficients have no physical significance. This is a severe drawback. Estimation of individual end-uses was demonstrated by removing their presence in the NN model. However, due to the interconnectivity between each end-use, the removal of many end-uses, individually or simultaneously, reduces the level of confidence in the resulting predictions. Furthermore, bias of the energy estimation error was found when using the NN technique. Aydinalp-Koksal and Ugursal [**123**] provide a detailed review and comparison of specific CDA, NN, and EM models. Bottom-up EM techniques rely on more detailed housing information. These models explicitly calculate or simulate the energy consumption and do not rely on historical values, althoughhistorical data can be used for calibration. Larsen and Nesbakken [**124**] developed both engineering (samples) and statistical (CDA) models to compare their results. They noted that the engineeringtechnique requires many more inputs and has difficulty estimating the unspecified loads, but while the statistical technique reduces both of these issues it is hampered by multicollinearity resulting inpoor prediction of certain end-uses. If the objective is to evaluate the impact of new technologies, the only option is to use bottom-up EM techniques. This is a point of emphasis because compared to taxation and pricing policies, technological solutions are more likely to gain public acceptance to reduce energy consumption and the associated greenhouse gas emissions. The EM is capable of modeling on-site energy collectionor generation such as active or passive solar and co-generation technologies. The most apparent drawback of the EM is the assumption of occupant behaviour. Because the effect of occupant behaviour can significantly impact energy consumption, the assumption of occupants' activities is not trivial. Statistical techniques based on monthly data are capable of incorporating the effects of occupant behaviour, although they may be inappropriately applied to end-uses. Also, the high level of expertise required in the development and use of the EM may be considered a drawback.The computational limitations discussed by Griffith and Crawley [**38**] regarding large numbers of simulations are no longer critical as the data processing capability of computers is continuing toincrease rapidly. To address the shortcomings of both the EM and the statistical based models, research is currently being conducted by Swan et al. [**95**] to develop a ''hybrid'' EM and NN model for the Canadian housing sector that will incorporate a NN model to predict the highly occupant sensitive DHW and AL energy consumption, while using the EM to predict the SH and SC energy consumption.

5.19 Conclusions

Top-down approaches models are used mostly for supplying analysis based on long-term projections of energy demand by taking in account the historic response. Bottom-up statistical techniques models are used to identify the energy demand contribution of end-uses by introducing the behavioural aspects based on data obtained from energy authority and surveys. Bottom-up engineering techniques are used to explicitly calculate energy consumption of end-uses taking in account the detailed descriptions of a representative set of houses, and these techniques have the capability of determining the impact of new technologies. Given today's energy considerations that include supply, efficient use, and effects of energy consumption o the promotion of conservation, efficiency, and technology implementation, all three modeling approaches are useful. Top-down models are more useful in supply considerations because they are strongly weighted by historical energy consumption which makes their estimates of supply more accurate. Bottom-up statistical models can account for occupant behavior and use of major aggregates, this leads to the understand which of behaviors and end-uses cause more consumption of quantities of energy. Lastly, bottom-up engineering models may identify the impact of new technologies based on their characteristics and account for the wide degree of variety within the housing stock. To determine the impacts of such new developments requires a bottom-up model. More focus on efficiency and surveys on energy consumption generation at individual houses. In this fast technological development and implementation, the bottom-up techniques will likely provide much utility as policy and strategy development tools.

Although bottom-up building physics stock models are used to explicitly determine and quantify the impact of different combinations of technological measures on delivered energy use and CO2emissions, and therefore represent an important tool for policymakers, there are a number of different limitations associated with the models. The most important shortcoming of all these models istheir lack of transparency and quantification of inherent uncertainties. The lack of publicly available detailed data on the models'inputs and outputs, as well as underlying algorithms renders any attempt to reproduce their outcomes problematic. In addition, the relative importance of input parameter variations on the predicted demand outputs needs to be quantified as a matter of course. Currently, models often fail to deal adequately with the interactions that occur with different aspects of energy demand, particularly socio-technical factors. Specifically this reflects our lack of knowledge of how different people consume energy in their homes, how they use domestic technologies, and how they react to changes in the dwelling as a result of energy performance measures. Last but not least, the new generation of bottom-up building stock models should include multidisciplinary and dynamic approaches, so that for instance they can improve the synergy in policy development on energy efficiency, comfort, and health.

Conditional Restricted Boltzmann Machines for energy prediction in buildings to forecast the energy consumption in an office building using three statistical methods over a one week horizon with hourly resolution. The analysis performed showed that CRBM is a powerful probabilistic method which outperformed the state-of-the art prediction methods such as Artificial Neural Networks and Hidden Markov Models.

HEATING ENERGY CONSUMPTION RENOVATION STRATEGY

6 Introduction

As the results of the simulation performed by eQUEST, and according to the previous chapter, were very close to the recorded results of heat space energy consumption given by the utilities services in Riga, the software eQUEST will be used in the following chapter to investigate different scenarios of the effect of changing some of the building characteristics on energy consumption. The building envelope construction, the building interior construction, the external doors, the external windows, the building operation schedule, and the activity area allocation are introduced in these scenarios. The building concerned by the renovation belong to the kind of buildings that represents the largest number of buildings in a city in Latvia, and the largest number of buildings without retrofit.

6.1Literature works

Jinghua Yu et al.in his work titled *"Energy conservation of window systems in residential buildings of hot summer and cold winter zone in China",*used eQUEST software to analyze the effects of envelope factors on energy saving of AC, which included five single strategies of exterior wall thermal insulationabsorbance of exterior wall, ratio of window to wall, categories of glazing and kinds of shading system, and two combined strategies[**125**].The effect of heat-insulating on heating and cooling energy consumption of residential building in hot summer and cold winter zone have been studied in [**126**]. The influence of residential air conditioning load on the exterior wall heat insulation in hot summer and cold winter zone was studied in [**127**]. The impact of structure and environment on global energy consumption was developed in [**128**] . Al-Turki and Zaki[**129**] investigated the effect of insulation and energy storing layers upon the cooling load. Bolatturk [**130**] calculated the optimum insulation thicknesses, energy savings and payback periods. He used the heating degree-days concept to obtain the annual heating and cooling requirements of building in different climates zones. Durmayaz et al [**131**] estimated the heating energy requirement in building based on degree hour method on human comfort level. Some researchers used the life cycle cost analysis to optimize the insulation thickness in Hasan [**86**]. The effects of insulation on energy saving in Iranian building are studied by Farhanieh and Sattari [**132**]. Bakos [**133**] study the comparison in energy savings before and after application of thermal insulation in the exterior envelope. Natural gas consumed in heating by residential heating in terms of degree days is studied by Sarak and Satman [**134**]. A mathematical model was developed by Sofrata and Salmeen [**75**]to find the optimal insulation thickness. Mohammed and Khawaja [**135**] determined the optimum thickness of insulation for some insulating materials used in order to reduce the rate of heat flow to the building in hot countries, and he mentioned that the solar radiation has the most important factor. The effect of climatic zones on the choice of the insulation type, and thickness, has been studied by Al-Sallal [**136**] using the life cycle model. The life cycle cost analysis using the degree day was also used by Comakli and Yuksel [**137**] to investigate the optimum thickness of insulation for coldest cities in Turkey. Daous et all [**138**], used also life cycle cost analysis in order to determine the optimal insulation thicknessunder steady periodic conditions. Sisman et al. [**76**] determine the optimum insulation thickness for different degree day region in Turkey for a lifecycle number of years by taking into consideration the thermal conductivity and the price of insulation material, average temperature in the region, fuel price for heating and the present worth factor PWF. Dombayaci [**139**] studied the environmental impact of optimum insulation thickness; he used coal as a fuel source, and expanded polystyrene as insulation material. The effect of average electricity tariff on the optimum insulation thickness in building walls by using a dynamic heat transfer model and an economic model based on the present worth method was investigated by Al-Sanea et all [**140**].Mahlia et al [**22**] developed correlation between thermal conductivity and the thickness of selected insulation materials for building wall. Significant economic advantage in energy consumption can be seen by using insulation to achieve high performance building envelope was demonstrated by Lollini [**141**]. Ozel and Pihtili [**142**] used an implicit finite difference method for multi-layer wall during winter and summer to obtain the optimum location and distribution of insulation for all wall orientations. S.Ali Hussain Jafri [**143**] makes a review of some optimum insulation thickness for building envelope; he summarized previous references, the place, the insulation material and thermal conductivity, and components of building envelope. Alexander Gorshkov [**84**], et al. used the life cycle analysis to assess energy savings delivered by building insulation.

6.2 Building construction

6.2.1 Building envelope construction

The building envelope construction is composed of three main parts, roof surfaces, above grade walls, and ground floor, the roof surfaces and above grade walls characteristics are divided into five parts, construction, external finish and colour, exterior insulation, additional insulation and interior insulation. For construction, different scenarios can be fitted from eQUEST library such as wood frame standard, wood frame, wood frame 609.6mm, wood frame > 609.6mm, metal frame and, metal frame > 609.6mm, or it can be costumed layer by layer.

For external finish we can choose any material from the following: Aluminium, asphalt pavement, clay tile, concrete, felt, bituminous, film, Mylar aluminized, glass spandrel, gravel, marble, roof built up, roofing shingle, steel galvanized bright or weathered, vapour deposited low-e coating, and wood/plywood. For the colour we can choose any colour from dark to white, gloss or flat, or lacquer, we can also choose the colour according to the absorption coefficient.

Exterior insulation, polystyrene with standard thickness from 25.4mm, 38.1mm, 50.8mm,76.2mm,101.6mm,127mm, and 152.4mm may be used in our variables scenarios, then polyurethane with the thicknesses from 25.4mm, 38.1mm, 50.8mm,76.2mm,101.6mm,127mm, and 152.4mm, polyisocyanurate may also be used in our examples with the same standard thickness. Thermal values of polystyrene range from R-4(0.7 m^2K/W), for a thickness of 25.4mm, to R-30(5.8 m^2K/W) for a thickness of 152.4mm, values for polyurethane range from R-6(1.08 m^2K/W) for a thickness of 25.4mm, to a value of R-36(6.34 m^2K/W) for a thickness of 152.4mm, values of thermal resistance of insulation with polyisocyanurate varies from R-9 (1.58 m^2K/W) for a thickness of 2.54mm, to a value of R-42 (7.38 m^2K/W) for a thickness of 152.4mm.

Additional insulation are expressed in thermal values, and eQUEST software gives standard values of R-7 (1.23 m^2K/W), R-11(1.95 m^2K/W),R-13(2.35 m^2K/W), R-15(2.64 m^2K/W), R-19(3.34 m^2K/W),, R-21(3.69 m^2K/W), R-26(4.58 m^2K/W), R-30(5.27 m^2K/W), R-38(6.87 m^2K/W),R-49(8.63 m^2K/W),and R-60(10.56 m^2K/W).

Ground floor is defined by its exposure, on earth contact, over conditioned space (adiabatic), crawl space, unconditioned space, parking garage, or exposed to ambient conditions, the type of construction of the ground floor can be 50.8mm, 101.6mm, 152.4mm, or 203.2mm concrete, or 25.4mm to 50.8mm plywood underlayment. Exterior cavity insulation can be from polystyrene, polyurethane, polyisosyanurate, with different thickness ranging from 25.4mm,38.1mm.50.8mm,76.2mm,101.6mm,127mm, or with batt insulation with different R values ranging from R-3 (0.52 m^2K/W) to R-38(6.87 m^2K/W). Interior insulation could be from polystyrene, polyurethane,or polyisosyanurate, with different thicknesses and different R values from R-4(0.52 m^2K/W) to R-2(0.35 m^2K/W). Light concrete with thickness ranging from 31.75mm to 101.6mm can be used as internal finish; different kind of carpet with pad or without pad, fibre or rubber pad, tile from vinyl, ceramic or stones may be used as finish. When the slab penetrates the wall plan, the type of slab insulation could be the same as the insulation materials used before, and the slab edge finish can be aluminium, asphalt, brick, concrete, film, glass, marble, steel, stucco, vapour deposit, or wood/plywood.

6.2.2 Building interior construction

Building interior construction is divided in four main parts, the top floor ceiling (above attic), other floor ceiling, vertical walls, and floors. The top floor ceiling is composed of interior finish, framing, Batt insulation, and rigid insulation. Interior finish may be made of lay-In acoustic tile, drywall finish, or plaster finish. Batt insulation, framing is made of wood standard framing, wood advanced framing, or metal stud 609.6mm o.c. The batt insulation that could be added to the top floor ceiling have a standard R values ranging from R-3 ($0.53m^2K/W$) to R-60($10.56\ m^2K/W$). Rigid insulations that may be fixed on the top floor ceiling are polystyrene, polyurethane, or polyisocyanurate with a thickness of 2.48mm or 38.1mm. For other floor ceiling, between each level, interior finish could be the same as in the top floor ceiling, lay-In acoustic tile, dry wall finish or plaster finish. The batt insulation R values for other floor ceiling have values of R-11($1.95\ m^2K/W$), R-13($2.35\ m^2K/W$), R-19($3.34\ m^2K/W$), R21($3.69\ m^2K/W$), and R-30 ($5.27m^2K/W$). Floors are characterized by their internal finish, construction, concrete cab, and their rigid insulation. Internal finish may be made of carpet, carpet with rubber pad, carpet with fibre pad, vinyl tile or ceramic/stone tile. Construction may be made of 50.8mm to 203.2mm concrete, or 25.4mm to 50.8mm plywood underlayment. Concrete cap may be made of 31.75mm of lightweight concrete to 101.6mm LW concrete. Rigid insulation is made of polystyrene, polyurethane, ployisocyanurate, with thickness ranging from 25.4mm to 76.2mm.

6.2.3 Exterior doors

Exterior doors, three door types may be described, each type can be made of opaque door, overhead door, glass door, sliding glass, air lock entry, and revolving glass. Number of doors for each orientation is also considered. Doors dimensions (high and width in m), constructions and glass definitions (unglazed opening, single Visteon, single PPG,single pelkington, single clear, single reflective, single low-E, single electro, double clr, double AFG, double visteon, double cardinal, double guardian, double PPG, double viracon, double pilkington, double clr/tnt, double reflective,double low-E, double electro,trible clr, triple south wall, triple low-E, and quadruple low-E), as well as frame type (aluminium, wood or PVC) and width are usually taken 76.2mm ,are to be input in software. Two glass categories can be chosen, Sun-Guard, and Perf Plus II, and glass types are defined by the type of glass, clear or coloured, single glass or double glass, the thickness of the gap (3mm or 6mm), the type of gas filling the gap (Air, thin Air, Krypton, or Arg), for each type of glass, the U value and solar heat gain coefficient SHGC are specified. The frame type (Aluminium or Wood) and the frame width should also be specified. Opaque external doors are classified in steel or wood, steel doors are made of hollow core, or filled with insulation materials such as urethane foam, mineral insulation, polyurethane or polystyrene. Wood doors are made of hollow core flush, wood panels or wood solid core flush with different thicknesses.

6.2.4 Exterior windows

Windows area specification method is given according to the percentage of the area of the window to the percentage of the net wall area (floor to ceiling), or the percentage of the gross wall area (floor to floor), or the percentage of the conditioned floor area. The importance of the affection of window-wall ratio on energy consumption is explained in reference [**144**]. Glass category is the same as the one given for external doors made of glass. The glass type may clear/air/clear, bronze/air/clear, grey/air/clear, or green/air/clear, all with a thickness gap of 6mm, and with different U, and SHGC values. Frame type could be made of Aluminium, reinforced vinyl, wood/aluminium, wood/ vinyl, insulation fibreglass /vinyl, structural glaze, or ASHRAE Aluminium. Windows dimensions (width, height, and sill), positions, and quantities are fitted in the software. Estimated building wide-gross (floor to floor) % window is 13.3%, and net (floor to ceiling) is 15%. Exterior windows shade and blinds are to be specified, exterior windows shade overhangs and fins are placed in top floor only or in all windows. Blinds are horizontal/vertical blinds with light colour, medium colour or dark colour. Blinds may be present as a roller shade translucent, opaque, light colour, medium colour, or dark colour. Fabric drapes are made of light colour, medium, and dark colour.

6.3 Building operation schedule

The building operation schedule is nearly the same for all the working people, and it does not need to be changed, unless for a specific project, the day time unoccupied low use, typical use, or high use, schedule is that people leave at 7 am in the morning and return at 5pm in the evening for working days, for Saturdays, Sundays, and holidays, people leave at 9 and return at 4pm in evenings. Operation schedule can be also chosen as 24 hours operation low use, typical use, or high use.

6.4 Activity area allocation

Nearly all type of activity exists in the eQUEST library, examples from the running file are, auditorium, bank, casino, classroom, hotel, gymnasium, hall, laboratory, office , hospitals, religious, residential, and many others. The percentage of the occupied area, the design maximum occupation in square feet per person, and the design ventilation rate in cubic feet meter per person are to be indicated in the software.

The number of possibilities and scenarios that offer eQUEST for the roof construction is 6, for the exterior finish is 15, for the colour is 35, for exterior insulation is 22 and for additional insulation is 12, this make the number of scenarios possible for the roof is 831600 combinations. The same thing can be said for the above grade walls, and the floors. The building interior construction, external doors, external windows, external windows shade and blinds, building operation schedule and activity area allocation have more possible scenarios than the roof. This makes it nearly impossible to check the effect of each variable on energy consumption which led me to choose few combined scenarios.

6.5 Different scenarios

The building chosen to be considered in the following is a multi-family mid rise, and is situated at Lēdurgas street, number 7, Riga, Latvia, the weather data file for Latvia is used, the building area is measured in m^2 (2072.01 m^2), the number of levels is 5, and as a heating equipment a heating coil, the year 2010 is chosen for the simulation. The roof is not pitched roof, but it is an 152.4mm attic above last floor.

The roof surfaces construction chosen are in metal frame 609.6mm,o,c. as external finish we choose asphalt pavement weathered, and medium colour of 0.6 abs.

For above grade walls, we choose for construction HW concrete of width 101.6mm, with no external finish, with a medium absorption of 0.6, and 50.8 mm polystyrene as external insulation.

For floor, the exposure over crawl space was chosen, the construction chosen is 101.6mm concrete, the external insulation 50.8mm polystyrene R-8 (1.44m^2K/W), interior insulation used 25.4mm polystyrene and as a finish 31.75mm of LW concrete and vinyl tile, and there was no board insulation or finish selected for slab edge penetring wall plane. Figure 6.1shows the building envelope construction window in eQUEST.

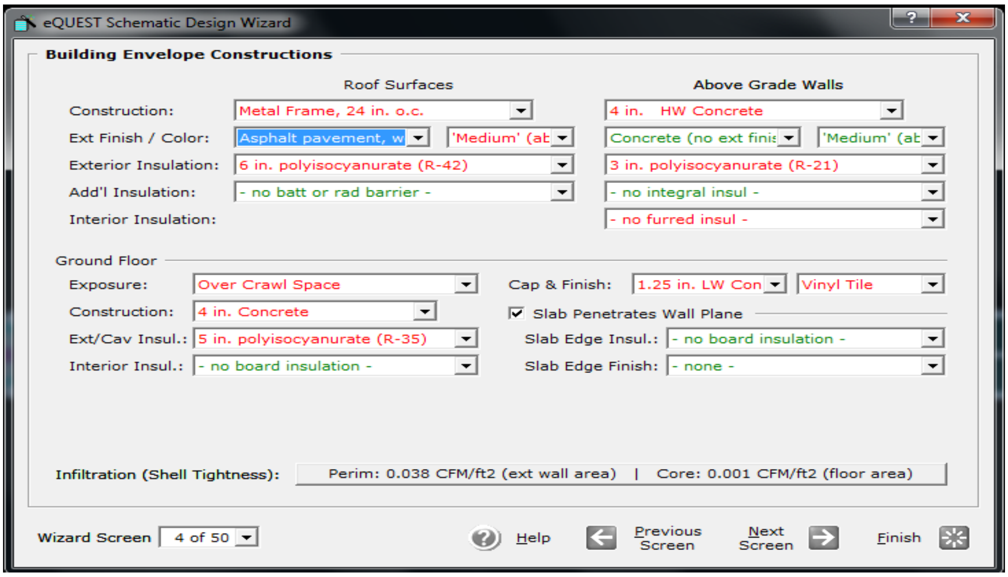

Figure 6.1 Building envelope construction window

For the building interior construction, the top floor ceiling (bellow attic) has as interior finish, R-38 (6.87m^2K/W) is chosen as batt insulation, to dry wall finish, and 609.6mm metal stud as framing with no rigid board insulation. Vertical walls type is taken Mass. Vinyl tiles are chosen for floors interior finish, with no board insulation, the construction type for floors is concrete of 101.6mm thickness, the concrete caps taken 31.75mm in light weight concrete. There is no board insulation, or special finish for slab edge penetrating wall plane (figure 6.2).

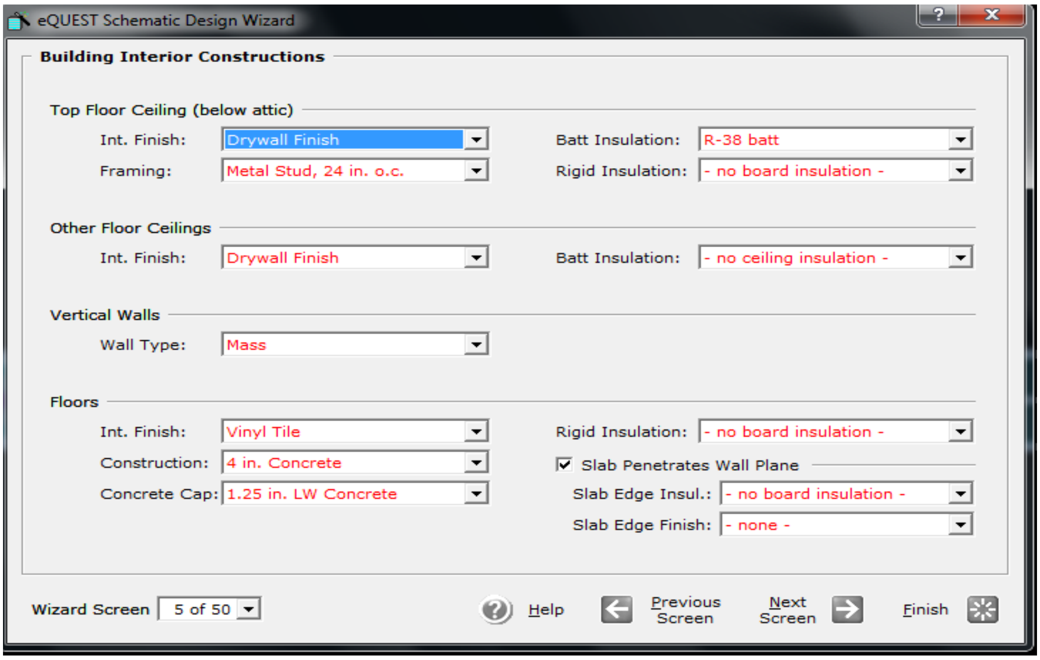

Figure 6.2Building interior construction.

The orientation of the external door is west, it is opaque, and made of steel hollow core. The main door dimensions are height 2.13 m and width 1.82m.

For exterior windows area specification, the percentage of net wall area (floor to ceiling) is chosen. The glass category chosen is single glazing, clear or light tinted, with a width of 3mm (U value = 1.04, SHGC = 0.86, and VT =0.9). The frame type taken as Aluminium fixed. External windows dimensions are 1.22m width, 1.37m height, and a sill of 0.91m. The percentage of windows floor to ceiling is taken 15% for both east and west orientation, with no shade or blinds figure 6.3.

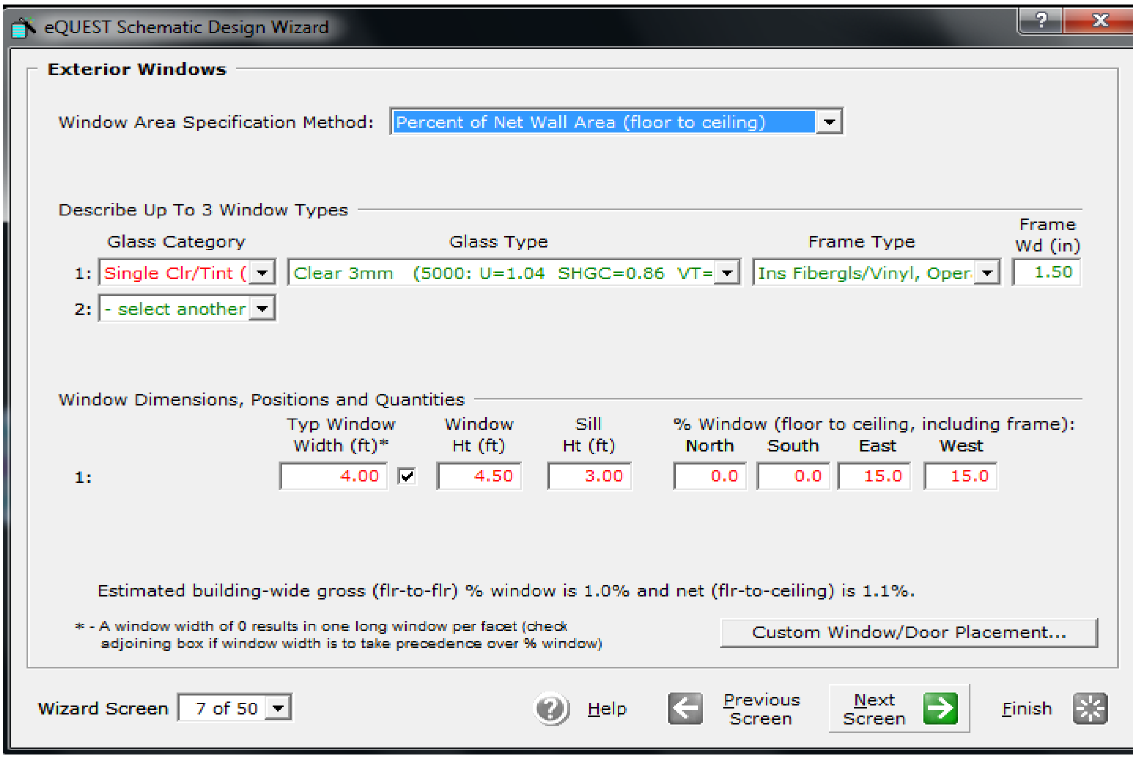

Figure 6.3Exterior window.

The building operation schedule for entire year from the 1st January to 31st of December is represented for the whole week as the following: from Monday to Friday, return at 5 pm, and leave at 7 am, for Saturdays, Sundays and holidays, leave at 9 am and return at 4 pm, day time the flats are supposed to be not occupied. Activity area allocations, percent area for multi-family, corridor storage, together with a maximum occupation and ventilation rate are chosen according to the previous table 3.3

For residential dwellings, interior consumption contributing to internal load are interior lighting, cooking and miscellaneous equipment, external loads are external lighting and domestic hot water. Interior lighting is taken as 5.38W/m^2, in the corridor is taken as 6.13W/m^2, in storage is taken as 12.8W/m^2, and in laundry as 137.7W/m^2, cooking loads profile for gas or electric cooker are not taken in consideration.

For heating primary equipment, hot water loop head is taken 11.15m and design DT is taken 4.45°C, hot water loop flow is taken constant, with a single pump, hot water is supposed to be heated by natural gas, the boiler efficiency is 80%. The hot water system schedule for the entire year is following the operation schedule, from Monday to Friday, return at 5 pm, and leave at 7 am, for Saturdays, Sundays and holidays, leave at 9 am and return at 4 pm, the set value is fixed at 82.23°C. For the residential domestic hot water is modelled using a value of 75.8 l/person/day, with an input rating value of 588.8 kW, and with a thermal efficiency of 0.8. The water supply temperature is 43.33°C.

The simulation results for electrical energy consumption are given in MWh, but for space heating and domestic hot water [**145**].

6.6 Strategies

Three mean strategies were adopted for the analysis of the effects of varying insulation type and thickness on annual heating space energy consumption. The first strategy is to act upon the external building envelope insulation, by changing the thickness and the type, while keeping all the others, interior building insulation and windows type and categories constant. The external building envelope is divided in three parts, exterior insulation for roof, above grade wall (vertical wall), and ground floor. The second strategy is to act upon interior construction, by changing the thickness of batt insulation while keeping all others constant. The interior construction is divided in three parts as well, top floor ceiling (under attic), other ceiling, vertical walls, and floors, but vertical walls, other ceiling and floors were kept constant without variation during these scenarios. The third strategy is to act upon exterior windows type and glazing on space heating energy consumption.For the external building envelope insulation three type of insulation were used, the polystyrene, the polyurethane, and the polisoycynurate with different thicknesses, we choose small, medium and large insulation thicknesses. The following table 6.1 summarizes the different insulation scenarios.

Table 6.1Sumarizes the differents insulation scenarios.

Scenarios	Insulation type	Thickness mm	Roof insulation	Above grade wall	Ground floor
1	Polystyrene	thickness	50.8	50.8	50.8
2	Polystyrene	thickness	101.6	76.2	101.6
3	Polystyrene	thickness	152.4	76.2	127
4	Polyurethane	thickness	50.8	50.8	50.8
5	Polyurethane	thickness	101.6	76.2	101.6
6	Polyurethane	thickness	152.4	76.2	127
7	polyisocynurate	thickness	50.8	50.8	50.8
8	polyisocynurate	thickness	101.6	76.2	101.6
9	polyisocynurate	thickness	152.4	76.2	127

6.6.1 Polystyrene thicknesses effects on space heating energy consumption

The results of the comparaison of the space heating annual energy consumption, when acting upon building exterior envelope insulation by changing the thickness of the insulation material while maintaning the other factors constant, to eveluate only the effect of adding more insulation using the same type (polystyrene in Scenarios 1,2, and 3), are summarized in figure 6.4. In the first scenario, the polystyrene thicknessesare 50.8mm for roof, wall, and floor. In the second scenario, the polystyrene thicknesses are 101.6mm for the roof, 76.2mm for the wall, and 101.6mm for the floor, and in the third scenario 152.4mm insulation for the roof, 76.2mm for the wall, and 127mm for the floor. The results are given in MWh and are summarized in Figure 6.4[**146**]

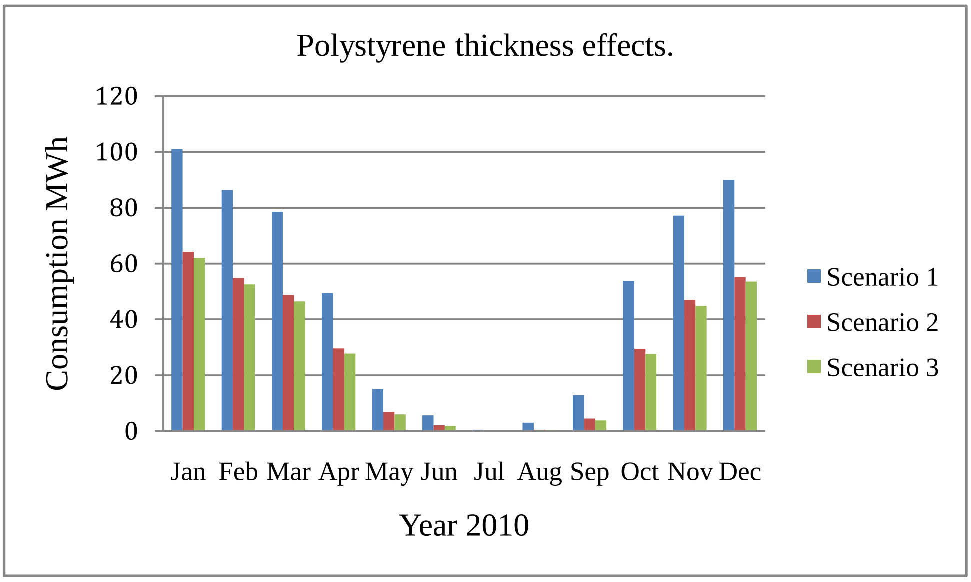

Figure 6.4 Polystyrene thickness effects on energy consumption

6.6.2 Polyurethane thicknesses effects on space heating energy consumption

The results of the thickness variation of the polyurethane used as insulation material for the building envelope(roof, wall, and floors), on the space heating annual energy consumption when keeping the other factors constant, are given in Figure 6.5. The insulation material thickness used in scenario 4,5, and 6are the same as in scenariosone,two and three. In scenario 4, the polyurethane thickness are 50.8mm for roof, 50.8mm for the wall, and 50.8mm for the floor. In the fifth scenario, the polyurethane thickness are 101.6mm for the roof, 76.2mm for the wall, and 101.6mm for the floor, and in the sixth scenario 152.4mm insulation for the roof, 76.2mm for the wall, and 127mm for the floor. The results are illustrated in Figure 6.5[**146**]

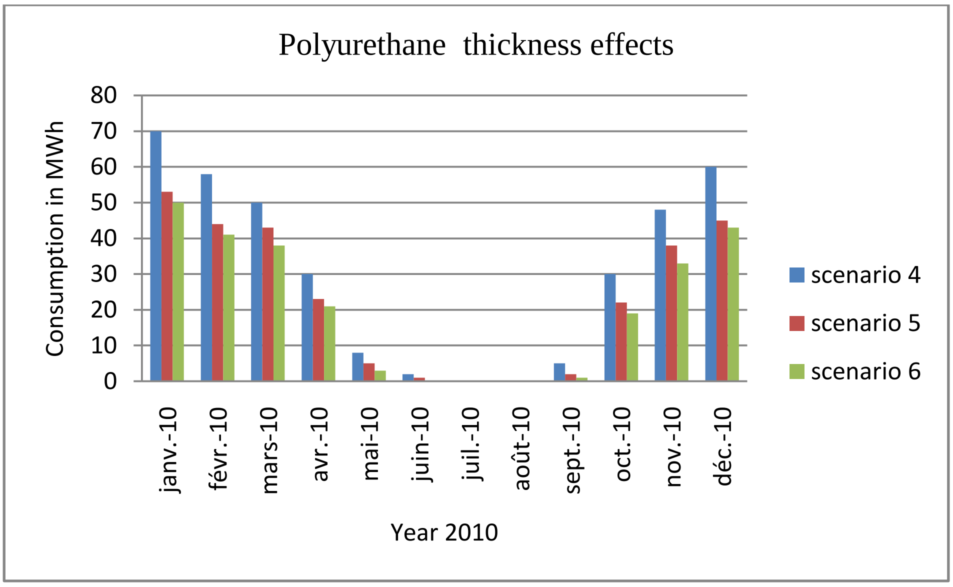

Figure 6.5 Polyurethane thickness effects on energy consumption.

6.6.3 Polyisocyanurate thicknesses effects on space heating energy consumption

The results of the variation of the thickness of the polyisocynurate used as insulation material for the building envelope(roof, wall, and floors), on the space heating annual energy consumption when keeping the other factors constant,are given in Figure 4.6. In the 7th scenario, the polyisocyanurate thickness are 50.8mm for roof, 50.6mm for the wall, and 50.8mm for the floor. In the 8th scenario, the polyisocynurate thickness are 101.6mm for the roof, 76.2mm for the wall, and 101.6mm for the floor, and in the 9th scenario 152.4mm insulation for the roof, 76.2mm for the wall, and 127mm for the floor. The results are illustrated in Figure 6.6[**146**]

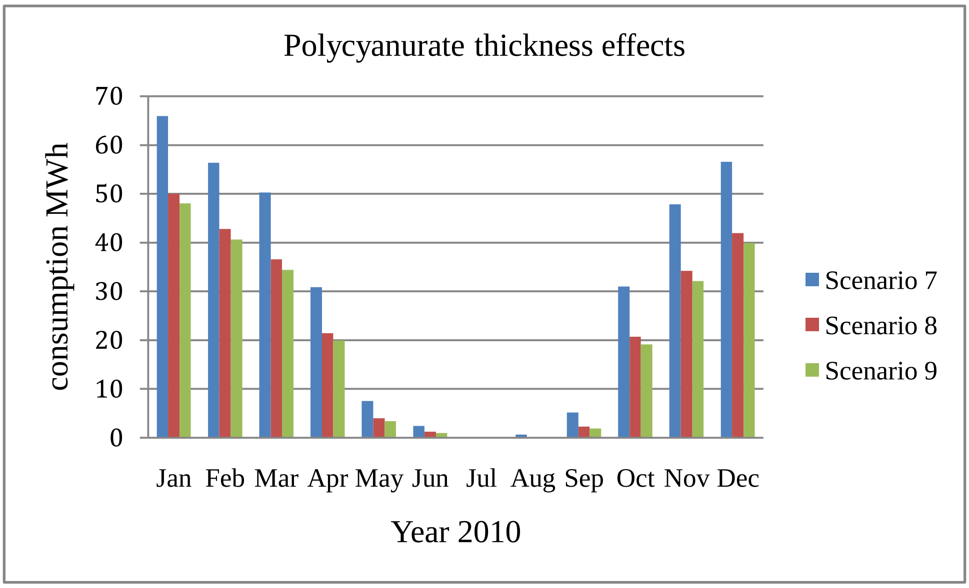

Figure 6.6 Polyisocyanurate thickness effects on energy consumption.

6.6.4 Comparison of energy consumption for small thickness of different insulations types

The comparison between different insulation materials with the same thickness are shown in the figure 6.7, the scenario 1 refers to the polystyrene material with 50.8mm thickness used for roof, 50.8mm for wall, and 50.8mm for floor, the scenario 4 refers to the polyurethane insulation material with the same thickness as for the polystyrene. And scenario 7 refers to the insulation material polyisocyanurate of 50.8mm thickness for roof, wall and floor. The results are illustrated in Figure 6.7

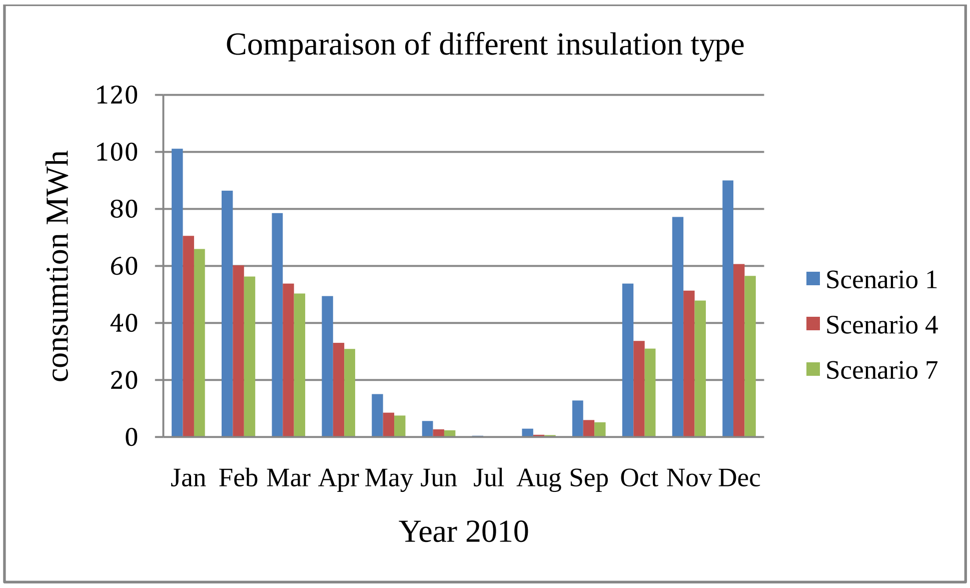

Figure 6.7 Comparison of different insulation type small thickness.

6.6.5 Comparison of energy consumption for medium thickness of different insulations types

The comparison between different insulation materials with medium thickness are shown in the figure 6.8, the scenario 2 refers to the polystyrene material with 101.6mm thickness used for roof, 76.2mm for wall, and 101.6mm for floor, the scenario 5 refers to the polyurethane insulation material with the same thickness as for the polystyrene. Scenario 8 refers to the insulation material (polyisocyanurate) of 101.6mm thickness for roof, 76.2mm for wall, and 101.6mm for floor. The results are illustrated in Figure 6.8

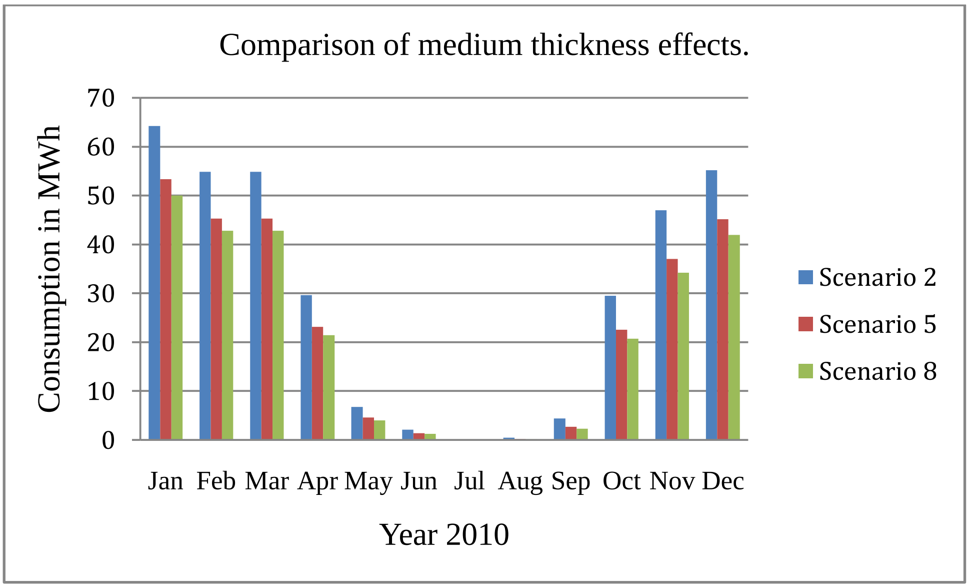

Figure 6.8 Comparison of different insulation type medium thickness.

6.6.6 Comparison of energy consumption for large thickness of different insulations types

The comparison between different insulation materials with large thickness are shown in the figure 6.9, the scenario 3 refers to the polystyrene material with 152.4mm thickness used for roof, 76.2mm for wall, and 127mm for floor, the scenario 6 refers to the polyurethane insulation material with the same thickness as for the polystyrene while scenario 9 refers to the insulation material (polyisocyanurate) of 152.4mm thickness for roof, 76.2mm for wall, and 127mm for floor. The results are illustrated in Figure 6.9

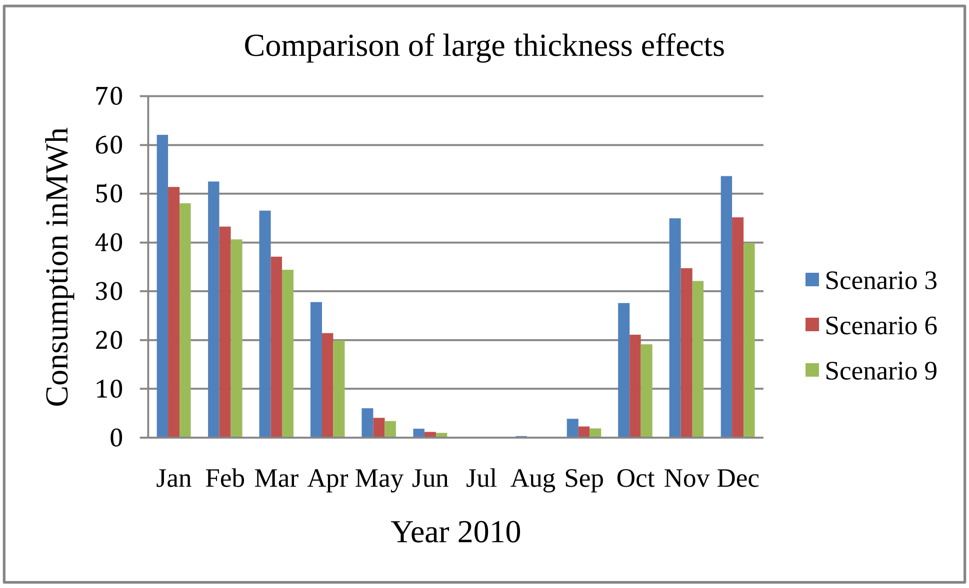

Figure 6.9 Comparison of different insulation type medium thickness.

6.7 Results

6.7.1 Effects of different polystyrene thicknesses on energy consumption

The effect of variating thickness of polystyrene for the external envelope, roof, wall, and floor, for the heating season in Latvia shows that when moving from scenario 1 to scenario 2, 36.47% of energy can be saved for the month of january, 36.51% for the month of february, 37.90%, for march, 45.20% for october, 39.13 % for november, and 38.62 for december, with a average of 38.49% for the heating season. While, when moving from scenario 2 to scenario 3, the gain percentage of saved energy is 38.61% of energy can be saved for the month of january, 39.26% for the month of february, 40.78%, for March, 48.64% for october, 41.72 % for november, and 40.42 for december, with a average of 40.01% for the heating season. The percentage difference between scenario 2 and scenario 3 is 2.15% for January, 2.75 for february, 2.88 fro march, 3.44 for october, 2.58 for november, and 1.79 for december, with an overall average of 2.52%. As a conclusion the use of scenario 2 (101.6mm for roof, 76.2mm for wall, and 101.6mm for floor) and insulation for external envelope is more convenient than scenario 3 (152.4mm roof, 76.2mm wall, 127mm floor). The mean different percentage of gain is only 2.52%. while the percentage of added thickness of insulation is 33.33% for the roof insulation and 20% for the floor insulation, the wall insulation remains with the same thickness 76.2mm. Table 4.2 summarises effect of polystyrene thickness on energy consumption for scenarios 1,2, and 3.

Table6.2 Effect of polystyrene thichness on energy consumption

	Jan.	Feb.	Mar.	Oct.	Nov.	Dec.	Mean
Scenario 1	101.099	86.43	78.54	53.79	77.19	89.98	81.17
Scenario 2	64.23	54.87	48.77	29.47	46.98	55.22	49.92
Gain %	36.47	36.51	37.9	45.2	39.13	38.62	38.49
Scenario 3	62.06	52.5	46.51	27.62	44.99	53.61	47.88
Gain %	38.61	39.26	40.78	48.64	41.72	40.42	41.01
(S3-S2) %	2.15	2.75	2.88	3.44	2.58	1.79	2.52

6.7.2 Effects of different polyurethane thicknesses on energy consumption

The effect of varying thickness of polyurethane for the external envelope, roof, wall, and floor, for the space heating season, shows that when moving from scenario 4 to scenario 5 energy can be saved by 24.43% for the month of january, 24.74% for the month of february, 26.94% for march, 33.07% for october, 27.87 % for november, and 25.62 for december, with a average of 26.53% for the heating season. While, when moving from scenario 5 to scenario 6, the gain percentage of saved energy is 27.17% of energy can be saved for the month of january, 28.11% for the month of february, 30.97%. for march. 37.42% for october, 32.32 % for november, and 28.66 for december, with a average of 30.78 % for the heating season. The percentage difference between scenario 5 and scenario 6 is 2.74% for january, 3.36 for february, 4.03 formarch, 4.35 for october, 4.45 for november, and 3.04 for december, with an overall average of 3.66%. As a conclusion the use of scenario 4 (101.6mm for roof. 76.2mm for wall. and 101.6mm for floor) as insulation for external envelope is more convenient than scenario 6 (152.4mm roof. 76.4mm wall. 127mm floor). The mean different percentage of gain is only 3.66%, while the percentage of added thickness of insulation is is 33.33% for the roof insulation and 20% for the floor insulation. the wall insulation remains with the same thickness 76.2mm.

Table 6.3 Effect of polyurethane thichness on energy consumption.

	Jan.	Feb.	Mar.	Oct.	Nov.	Dec.	Mean
Scenario 4	70.59	60.21	53.79	33.69	51.35	60.68	55.05
Scenario 5	53.35	45.31	39.3	22.55	37.04	45.13	40.45
Gain %	24.43	24.74	26.94	33.07	27.87	25.62	26.53
Scenario 6	51.41	43.29	37.13	21.08	34.75	43.29	23.68

Gain %	27.17	28.11	30.97	37.42	32.32	28.66	30.78
(S6-S5)%	2.74	3.36	4.03	4.35	4.45	3.04	3.66

6.7.3 Effects of different polyisocyanurate thicknesses on energy consumption

The effect of varying thickness of polyisocynurate for the external envelope, roof, wall, and floor, for the space heating season, shows that when moving from scenario 7 to scenario 8. energy can be saved by 24.19% for the month of january, 24.05% for the month of february, 27.29%, for march, 33.14% for october, 28.45 % for november, and 25.82 for december, with a average of 27.16% for the heating season. While, when moving from scenario 8 to scenario 9, the gain percentage of saved energy is 27.12% of energy which can be saved for the month of january, 27.80% for the month of february, 31.60%, for March, 38.07%, for october, 32.86 % for november, and 29.45 for december, with a average of 31.15 % for the heating season. The percentage difference between scenario 8 and scenario 9 is 2.63% for January, 3.75 for february, 4.31 for march, 4.92 for october, 4.41 for november, and 3.63 for december, with an overall average of 3.99%. In conclusion the use of scenario 8 (101.6mm for roof, 76.2mm for wall, and 101.6mm for floor) as insulation for external envelope is more convenient than scenario 9 (152.4mm roof, 75.2mm wall, 127mm floor).

The mean different percentage of gain is only 3.99%. while the percentage of added thickness of insulation is is 33.33% for the roof insulation and 20% for the floor insulation, the wall insulation remains with the same thickness 76.2mm.

Table 6.4 Effect of polyisocyanurate thichness on energy consumption.

	Jan.	Feb.	Mar.	Oct.	Nov.	Dec.	Mean
Scenario 7	65.96	56.34	50.3	30.97	47.83	56.57	51.33
Scenario 8	50	42.79	36.57	20.7	34.22	41.79	37.71
Gain %	24.19	24.05	27.29	33.14	28.45	25.82	27.16
Scenario 9	48.07	40.68	34.4	19.18	32.11	39.914	35.73
Gain %	27.12	27.8	31.6	38.07	32.86	29.45	31.15
(S9-S8) %	2.93	3.75	4.31	4.92	4.41	3.63	3.99

6.7.4 Comparison of polystyrene, polyurethane and polisocyanurate small thickness on energy savings

The comparison between the different types of insulation used in external building envelope shows that the use of 50.8mm thickness of polyurethane saves space heating energy consumption during heating period by 30.17% in January, 30.34% in February, 31.52 %in March, 37.35% in October, 33.47% in November, and 32.56% in December, with a mean percentage value of 32.57%. The use of polyisocyanurate as insulation for building envelope shows that when using of 50.8mm thickness, space heating energy consumption during heating period is reduced by 34.75% in January, 34.82% in February, 35.96 %in March, 42.42% in October, 38.03% in November, and 37.13% in December, with a mean percentage value of 37.18%. Table 4.5 gives the comparison of different insulation types on energy consumption small thicknesses.

Table 6.5 Comparison of different insulation types small thicknesses

	Jan.	Feb.	Mar.	Oct.	Nov.	Dec.	Mean
Scenario 1	100.89	86.43	78.54	53.79	77.19	89.98	81.17
Scenario 4	70.59	60.21	53.79	33.69	51.35	60.68	55.05
Gain %	30.17	30.34	31.52	37.35	33.47	32.56	32.57
Scenario 7	65.96	56.34	50.3	30.97	47.83	56.57	51.33
Gain %	34.75	34.82	35.96	42.42	38.03	37.13	37.18
(S7-S4) %	4.58	4.48	4.44	5.07	4.56	4.56	4.62

As a conclusion the use of polyurethane and polyisocyanurate as insulation for external envelope seems to be more efficient than using polystyrene, with the same thickness of 50.8mm each. The mean percentage of energy saved in space heating when using polyurethane is 32.57%. and when using the polyisocynurate is 37.18% with a difference of 4.62% between polyurethane and polyisocynurate. If the price difference is large between polyurethane and poliisocynurate,then the most efficient insulation to be used is the polyurethane as illustrated in Figure 6.5.

6.7.5 Comparison of polystyrene, polyurethane and polisocyanurate medium thickness on energy savings

The comparison between the medium thickness of different types of insulation used in external building envelope(101.6mm for the roof, 76.2mm for the wall, and 101.6mm for the floor) shows that the use of 101.6mm, 76.2 mm and 101.6mm thickness of polyurethane compared to the use of polystyrene with the same thicknesses, reduces space heating energy consumption during heating period by 16.94% in January, 17.42% in February, 19.42 %in March, 23.48% in October, 21.16% in November and 18.27% in December, with a mean percentage value of 19.45%. The use of polyisocyanurate as insulation for building envelope shows that when using the same thicknesses space heating energy consumption during heating period is reduced by 22.15% in January, 22.02% in February, 25.02 %in March, 29.75% in October, 27.15% in November, and 24% in December, with a mean percentage value of 25.02%. Table 4.6 gives the comparison of different insulation types on energy consumption medium thicknesses.

Table 6.6 Comparison of different insulation types medium thicknesses

	Jan.	Feb.	Mar.	Oct.	Nov.	Dec.	Mean
Scenario 2	64.23	54.87	48.77	29.47	46.98	55.22	49.92
Scenario 5	53.35	45.31	39.3	22.55	37.04	45.13	40.45
Gain %	16.94	17.42	19.42	23.48	21.16	18.27	19.45
Scenario 8	50	42.79	36.57	20.7	34.22	41.97	37.71
Gain %	22.15	22.02	25.02	29.75	27.15	24	25.02
(S8-S5) %	5.21	4.6	5.59	6.27	5.99	5.74	5.57

In conclusion the use of polyurethane and polyisocyanurate as insulation for external envelope seems to be more efficient than using polystyrene with the same thickness. The mean percentage of energy saved in space heating when using polyurethane is 19.45%, and when using the polyisocynurate is 25.02% with a difference of 5.57% between polyurethane and polyisocynurate. If the price difference is large between polyurethane and poliisocynurate. then the most efficient insulation to be used is the polyurethane. Results are shown in Figure 6.8.

6.7.6Comparison of polystyrene,polyurethane, and polyisocyanurate large thickness on energy savings

The comparison between large thickness of different types of insulation used in external building envelope(152.4mm for the roof, 76.2mm for the wall, and 127mm for the floor) shows that the use of 152.4mm,76.2mm, and 127 mm, thickness of polyurethane compared to the use of polystyrene with the same thicknesses is more efficient, and reduces space heating energy consumption during heating period by 17.16% in January, 17.54% in February, 20.18 %in March, 23.67% in October, 22.75% in November, and 15.81% in December, with a mean percentage value of 19.52%. The use of polyisocyanurate as insulation for building envelope shows that when using the same thicknesses, space heating energy consumption during heating period is reduced by 22.54% in January, 22.51% in February, 26.04 %in March, 30.57% in October, 28.62% in November, and 25.55% in December, with a mean percentage value of 25.97%. Table 4.7 gives the comparison of different insulation types on energy consumption large thicknesses.

Table 6.7 Comparison of different insulation types medium thicknesses

	Jan.	Feb.	Mar.	Oct.	Nov.	Dec.	Mean
Scenario 3	62.06	52.5	46.51	27.62	44.99	53.61	47.88
Scenario 6	51.41	43.29	37.13	21.08	34.75	45.13	38.8
Gain %	17.16	17.54	20.18	23.67	22.75	15.81	19.52
Scenario 9	48.07	40.68	34.4	19.18	32.11	39.91	35.72
Gain %	22.54	22.51	26.04	30.57	28.62	25.55	25.97
(S3-S2) %	5.39	4.97	5.86	6.9	5.87	9.74	6.45

In conclusion the use of polyurethane and polyisocyanurate as insulation for external envelope seems to be more efficient than using polystyrene, with the same thickness. The mean percentage of energy saved in space heating when using polyurethane is 19.52%, and when using the polyisocynurate is 25.97% with a difference of 6.45% between polyurethane and polyisocynurate. The most efficient insulation to be used is the polyurethane. Figure 6.9 illustrates th comparison of different insulation material types with a small thickness.

6.8 Conclusion

The use of polystyrene with differents thicknesses, small scenario1, medium scenario 2, and large senario 3, shows that the most convenient result is given by scenario 2 (101.6mm for roof, 76.2mm for wall, and 101.6mm for floor).Although the use of large thickness polystyrene insulation [scenario 3 (152.4mm roof, 76.2mm wall, 127 mm floor)] for external envelope reduces the heating energy consumption, but with a small percentage compared to the percentage of the increase in the polystyrene thickness. The mean different percentage of gain is only 2.52%. while the percentage of added thickness of insulation is 33.33% for the roof insulation and 20% for the floor insulation, the wall insulation remaining with the same thickness of 76.2mm.The use of polyurethane with medium thickness, scenario 5 (101.6mm for roof, 76.2mm for wall, and 101.6mm for floor) as insulation for external envelope is more convenient than polyurethane with large thickness,scenario 6 (152.4mm roof, 76.2mm wall, 127mm in floor). The mean different percentage of gain is only 3.66%. while the percentage of added thickness of insulation is 33.33% for the roof insulation and 20% for the floor insulation while wall insulation remains with the same thickness of 76.2mm.The use of polyisocinurate scenario 8 (101.6mm for roof, 76.2mm for wall, and 101.6mm for floor) as insulation for external envelope is more convenient than scenario 9 (152.4mm roof, 76.2mm wall, 127mm in floor). The mean different percentage of gain is only 3.99% while the percentage of added thickness of insulation remains with the same thickness as in previous scenario.In conclusion the use of polyurethane and polyisocyanurate as insulation for external envelope seems to be more efficient than using polystyrene, with the same thickness of 50.8mm each. The mean percentage of energy saved in space heating when using polyurethane is 32.57%. and when using the polyisocynurate is 37.18% with a difference of 4.62% between polyurethane and polyisocynurate. If the cost difference is large between polyurethane and polyisocynurate. then the most efficient insulation to be used is the polyurethane.The conclusion of the use of polyurethane and polyisocyanurate as insulation for external envelope seems to be more efficient than using polystyrene. with the same thickness.

The mean percentage of energy saved in space heating when using polyurethane is 19.45%. and when using the polyisocynurate is 25.02% with a difference of 5.57% between polyurethane and polyisocynurate. If the cost difference is large between polyurethane and polyisocynurate. then the most efficient insulation to be used is the polyurethane.Asa conclusion the use of polyurethane and polyisocyanurate as insulation for external envelope seems to be more efficient than using polystyrene with the same thickness. The mean percentage of energy saved in space heating when using polyurethane is 19.52%. compared to the use of polystyrene,The use of polyisocynurate is 25.97% with a difference of 6.45% between polyurethane and polyisocynurate. The most convenient insulation to be used is the polyurethane.The following chart figure 6.10 shows the selected type of of insulation according to our strategy.

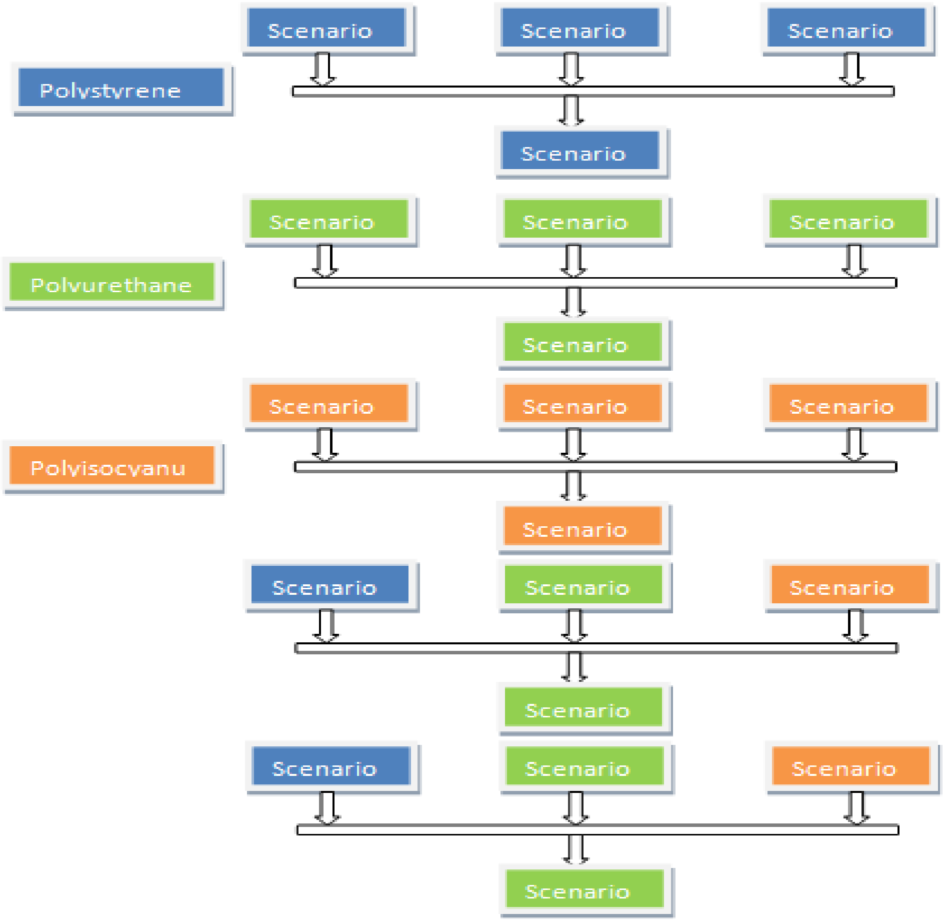

Figure 6.10 Scenario flow chart.

The chart in figure 6.10 summarizes the optimal thickness scenarios for the building envelope insulation. Scenarios 1(small layer means 50.8mm thick layer sheet of polystyrene added to the roof, the vertical externals walls, and to the floor), scenario 2 (medium thickness,101.6mm thick layer of polystyrene added to the roof, 76.2mm thick added to the vertical external walls, and 101.6 thick added to the floor), and scenario 3 (large thickness,152.4mm thick layer of polystyrene added to the roof, 76.2mm thich added to the vertical external walls, and 127mm thick added to the floor), represents the insulation with the small layerof polystyrene, (scenario1) , medium layer (scenario 2), and large layer (scenario3). Scenario 2was found to be the optimum. Scenario 4 (small layer), Scenario 5 (medium layer), and scenario 6(large layer) represents the polyurethane insulation thickness. Scenario 7, Scenario 8, and scenario 9 represents the polyisocyanurate insulation thickness , small, medium and large respectively. The comparison results shows that for all three type of insulation, the medium thickness was found to be the right choice (scenarios 2, 5, and 8). Whereas, the comparison between the different insulation type shows that, the polyurethane choice is the best fit for all thicknesses (scenarios 4, and 5).

6.9 Building interior insulation

As the simulation results for different batt insulation thermal resistance value were so close to each other for a different R values, where fiberglass was chosen as an insulation material for the ceiling with different thicknesses 279.4mm of fiberglass batts (R-38) with R value of 6.87m^{2}K/W, and 355.6mm (R-49) with R value of 8.63m^{2}K/W, and the last thickness is 508 mm of fiberglass batts (R-60) with R value of 10.56m^{2}K/W. The three values R-38. R-49.and R-60 were used in the simulation. The use of the building interior insulation for the top floor ceiling was negligeable and , hence, omitted from our analysis.

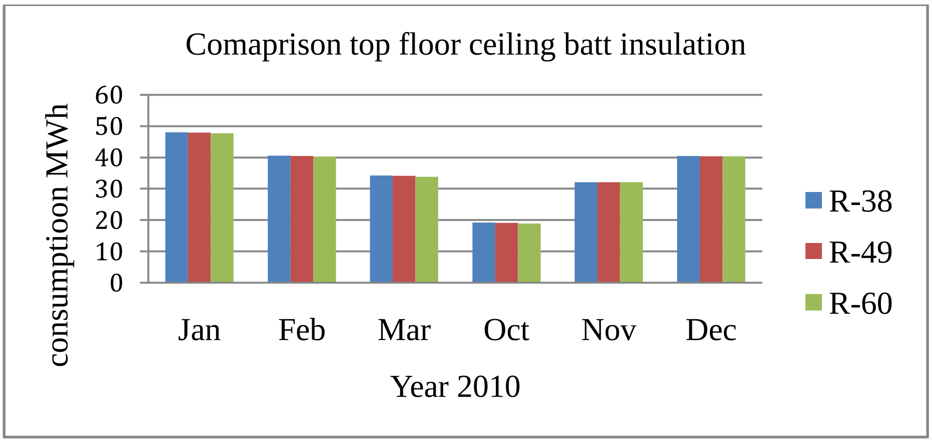

Figure 6.11 Top floor ceiling insulation effects.

6.10 Exterior windows

For the exterior type of windows, there is a large variety of glass categories, glass types while framing was kept constant for all the scenarios.

Only a few types and categories were checked in the following scenarios, covering the most used in buildings. Seven scenarios were tested using eQUEST library, in the first scenario, a single clear 3mm with U value of 1.04W/m^{2}K, and a fixed frame made from aluminium was tested, the second scenario, a double clear, clear/ThinAir/clear with a U value of 0.55 W/m^{2}Kand aluminium fixed frame was tested, the third scenario is a triple clear, clear/ThinAir/clear/Air/clear with a U value of 0.38W/m^{2}K.

The fourth scenario is single low-e clear, e4=0.4, 6.35mm, the fifth scenario is double low-e, e3=0.2, clear1/8, 6.35mm air. The sixth scenario, triple low-e, e5=0.1 clear 3.17mm. 6.35mm in air. The seventh scenario is quadruple low-e films, clear 3.17mm, 8.4mm krypton; they are summarized in Table 6.8.

Table 6.8 summarizes the different windows scenarios

Scenarios	Glass category	Glass type	Frame
1	Single clear	Clear 3 mm. U=1.04	Aluminium
2	Double clear	Clear/ThinAir/clear U=0.55	Aluminium
3	Triple clear	Clear/ThinAir/clear/Air U=0.38	Aluminium
4	Single low-e	e4=0.2clear3.17mm	Aluminium
5	Double low-e	e3=0.2. clear1/3.17mm.6.35mm Air	Aluminium
6	Triple low-e	e5=0.1 clear3.17mm.6.35mm Air	Aluminium
7	Quadruple low-e	Quadruple low-e Films. clear 3.17mm. 8.4mm krypton	Aluminium

6.11 Results and conclusions

6.11.1 Comparison between single, double and triple glass energy consumption

The comparison between glass categories, for single clear of 3 mm, double clear, and triple clear, using the eQUEST simulation software to estimate the energy consumed for the year 2010, for a multi-rise mid building in Riga, shows that the comparison between the space heating energy consumption for the three scenarios, when using windows with single glass, double glass, or triple glass, is not as large as in the exterior envelope. The consumption of single glass for the month of January 2010 is 48.33MWh, for double glass 45.84MWh, and for triple glass 45.37MWh. Table 6.9

Table 6.9 Different glass categories energy consumption

	Jan.	Feb.	March	October	November	December	Mean value
Scenario 1	48.33	40.53	34.31	19.41	32.55	41.26	36.06
Scenario 2	45.84	39.36	33.23	18.24	30.64	38.24	34.26
Scenario 3	45.37	38.97	32.9	17.94	30.26	37.51	33.83

The averages value of heating season energy consumption, from Oct to March, are 30.06 MWh for single glass windows, 34.26MWh for double glass window, and 33.83MWh for triple glass window. The comparison results between the three scenarios is illustrated in figure 6.12

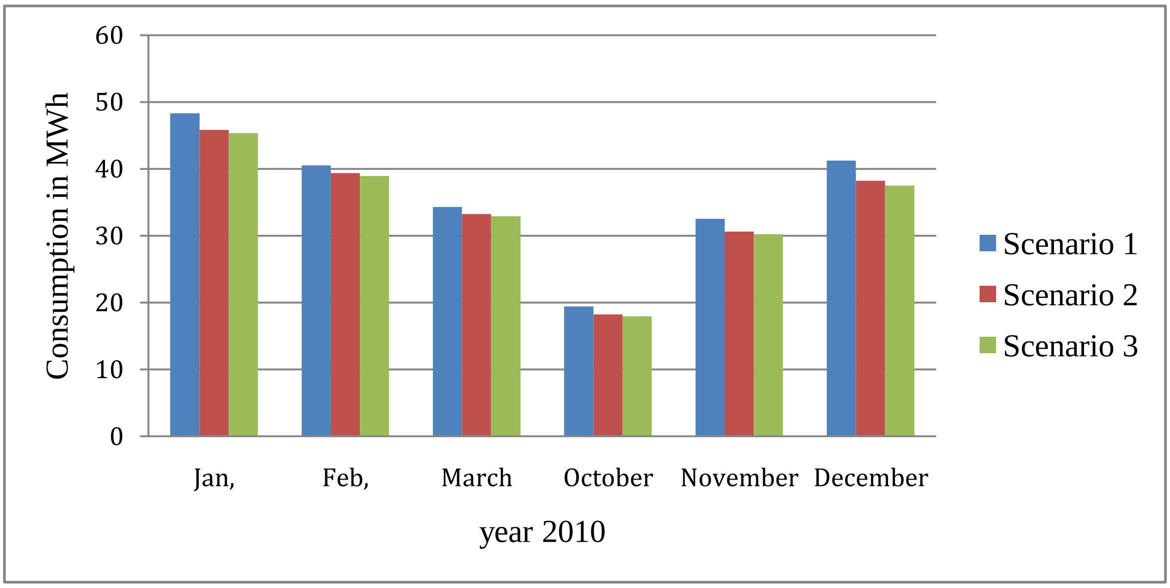

Figure 6.12 Comparison between single, double and triple glazing clear.

6.11.2 Comparison between single low-e, double low-e, triple low-e glass, and quadruple low-e glass energy consumption

The comparison between low –e glass categories, space heating energy consumption, for single low-e clear , with e4 = 0.4, and 3.17mm, double low-e clear with e3=0.2 clear, glass 3.17mm, air 6.35mm, triple low-e clear e5=0.1 clear, 3.17mm, 6.35mm Air, and quadruple low-e clear 3.17mm, 8.4mm krypton are illustrated in figure 6.13

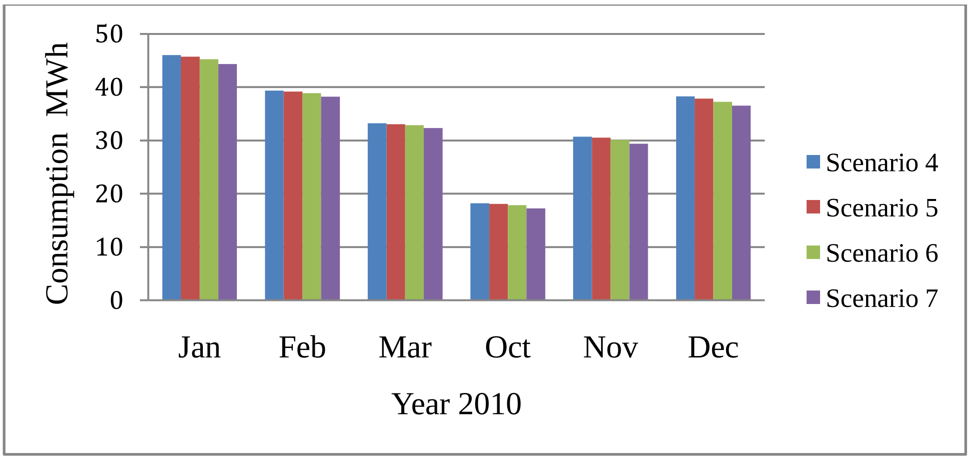

Figure 6.13 Low-e glass categories consumption.

The consumption of single low-e glass for the month of January 2010 is 46.01MWh, for double low-e glass 45.72MWh, for triple low-e glass 45.25MWh, and for quadruple low-e glass 44.37MWh, the values are reported in Table 4.10.

Table 6.10Low-e glass categories energy consumption year 2010

	January	February	March	October	November	December
Scenario 4	46.01	39.38	33.25	18.21	30.73	38.27
Scenario 5	45.72	39.18	33.05	18.09	30.53	37.86
Scenario 6	45.25	38.89	32.9	17.86	30.09	37.27
Scenario 7	44.37	38.21	32.35	17.247	29.38	36.51

Saved energy in the heating period when changing scenarios from single low-e, to double/triple/quadriple low-e is not very significant when compared to the percentage of energy saved by adding more insulation to the external envelope. The biggest difference appears between scenarios 6 and 7. The cost of different glass category will be more determinant in choosing the glass category and glass type than the effect of insulation. Figure 6.13 illustrates the difference in energy consumption for low-e glass type.

6.11.3 Comparison between single and single low-e, double and double low-e, triple and triple low-e

The results of the comparison between single and single low-e, double and double low-e, triple and triple low-e, and quadruple/quadruple low-e, are gathered in table 6.11

Table 6.11 Comparison of simple and low-e glass category

	Jan	Feb	Mar	Oct	Nov	Dec
Single	48.33	40.53	34.31	19.41	32.55	41.26
Single low-e	45.72	39.18	33.05	18.09	30.53	37.86
Double	45.84	39.36	33.23	18.24	30.64	38.24
Double low-e	45.72	39.18	33.05	18.09	30.53	37.86
Triple	45.37	38.97	32.9	17.94	30.26	37.51
Triple low-e	45.25	38.89	32.9	17.86	30.09	37.27

As can be seen from the results, that the difference in consumption of energy for the heating season shows, that the biggest difference occurs between single and single low-e, and quadruple and quadruple low-e, while it is insignificant for double/double low-e, and triple /triple low-e. Figure 6.14 gives the difference in energy consumption for different glass type (single/single low-e, double/double low-e, triple/triple low-e).

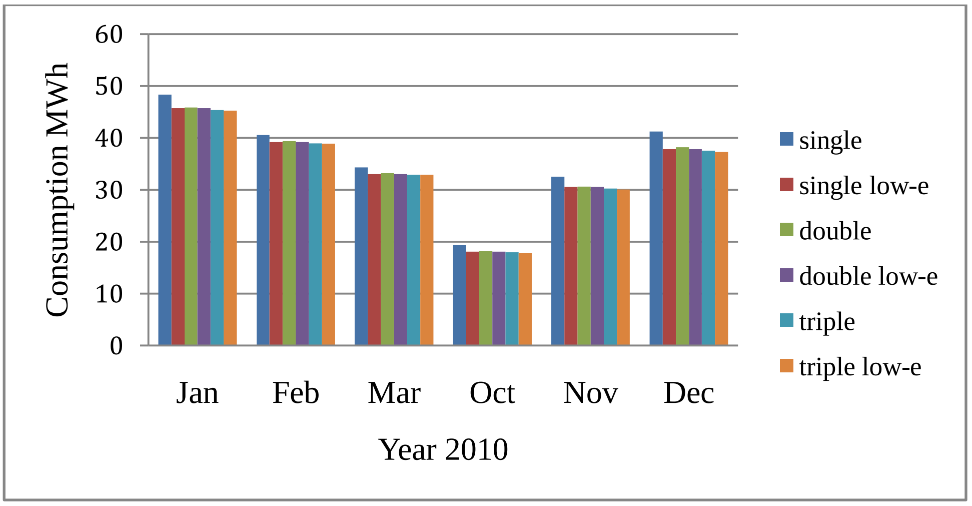

Figure 6.14 Difference in energy consumption for different glass types.

6.11.4 Comparison of single, double and triple clear glass.

Table 6.12Comparison Single, Double and Triple clear

	January	February	March	October	November	December	Mean value
Scenario 1	48.33	40.53	34.31	19.41	32.55	41.26	36.06
Scenario 2	45.84	39.36	33.23	18.24	30.64	38.24	34.26
Gain %	5.16	2.89	3.16	6.04	5.86	7.32	5.01
Scenario 3	45.37	38.97	32.9	17.94	30.26	37.51	37.86
Gain %	6.13	3.84	4.10	7.55	7.03	9.10	6.21
(S3-S2) %	0.97	0.94	0.94	1.51	1.17	1.78	1.19

As a conclusion of the comparison of single glass, double glass, and triple clear showed that, the mean monthly space heating energy consumption for scenario 1 (single clear) is equal to 36.06MWh, while it is equal 34.26MWh for scenario 2 (double clear) with a difference of 1.69MWh which represent 5% while the mean value of energy consumed for scenario 3 (Triple clear) is 45.37MWh with a difference percentage from scenario 2 is equal to just 1.26. This leads to the conclusion that when moving from single to double we have a gain of 5%, but when moving from scenario 2 to scenario 3 we have only 1.26% of benefit. The use of double glass category is optimal.

Table 6.13 Comparison single low-e .double low-e.triple low-e. and quadruple low-e

	January	February	March	October	November	December	average
Scenario 4	46.01	39.38	32.25	18.21	30.73	38.27	34.31
Scenario 5	45.72	39.18	33.05	18.09	30.53	37.86	34.07
Gain %	0.64	0.52	0.62	0.64	0.67	1.07	0.7
Scenario 6	45.25	38.89	32.9	17.86	30.09	37.27	33.71
Gain %	1.66	1.27	1.06	1.93	2.1	2.61	1.75
Scenario 7	44.37	38.21	32.35	17.24	29.38	36.51	33.01
Gain %	3.57	2.98	2.73	5.31	4.39	4.6	3.93

The mean monthly space heating energy consumption for single low-e (scenario 4) is equal to 34.31MWh, while the same value for double low-e (scenario 5) is equal to 34.07MWh with a difference of 0.24MWh between consumption in scenario 4 and scenario 5 The difference between double low-e and triple low-e mean value of energy consumed for space heating season is 0.36MWh, which represents a percentage of1.05%. The difference between triple low-e and quadruple low is 0.698MWh, which represents a percentage of 2.38 % of saved energy when compared to triple low-e consumption. As a conclusion, the main value of energy consumption single low-e and double low-e is nearly the same with 0.82% of difference while it remains also small but with a percentage of 1.23 for consumption between double low-e and triple low-e, and rise to 2.38 % for quadruple low-e. The use of double low-e is optimal.

6.11.5 Comparaison single/Single low-e, double/double low-e, triple/triple low-e

Table 6.14 Comparison single/Single low-e, double/double low-e, triple/triple low-e.

	Jan.	Feb.	Mar.	Oct.	Nov.	Dec.	Average
Single	48.34	40.53	34.32	19.42	32.56	41.27	36.07
Single low-e	45.73	39.18	33.05	18.10	30.53	37.86	34.08
Double	45.84	39.36	33.23	18.24	30.65	38.25	34.26
Double low-e	45.73	39.18	33.05	18.10	30.53	37.86	34.08
Triple	45.37	38.98	32.91	17.95	30.27	37.51	33.83
Triple low-e	45.26	38.89	32.91	17.86	30.09	37.28	33.71

The difference between heat space consumption when using single low-e instead of single is the most significant difference value. The difference between using single low-e and double is insignificant for the mean value of consumption of single low-e is 34.08 MWh for the heating season, while when using double is 34.26MWh, the mean value of consumption of double low-e is 34.08MWh, which equal to the single low-e value, for triple glass category, the mean consumption is 33.83MWh, the triple low-e consumption is 33.71MWh, with a difference from just triple with a difference of 0.62MWh bigger than the consumption of triple low-e, which is equal to 34.26MWh. The difference between double and double low-e is equal to 0.18MWh, and the difference between single and single low-e is 1.9MWh.The use of single low-e is optimal.As a general conclusion the comparison between single , double and triple clear glass category shows that the optimum is obtained for double clear, between single low-e, double low-e, triple low-e and quadruple low-e, the optimal values are single low-e and double low-e and quadruple low-e. The comparison between single/single low-e, double/double low-e, and triple/triple low-e, shows that single low-e, and double low-e, are optimal. The optimum is obtained for the double glazing low-e.

6.12 The new model strategy

The strategy maintainted in the chosen model, is built on the optimal material used in the model, the optimal material is not nessecary the most resistant to heat flow, but the most adequate according to both the thermal resistance and percentage of energy saving during the heating season. If insulation thickness or glazing type will only result in small pecentage of saving, then it will be excluded from the new model. Therefore the single low-emissivity is chosen for our new model as glass type, and the polyurethane with medium size as an insulation for the building envelope. The following chart shows the selected type of glass category according to our strategy.

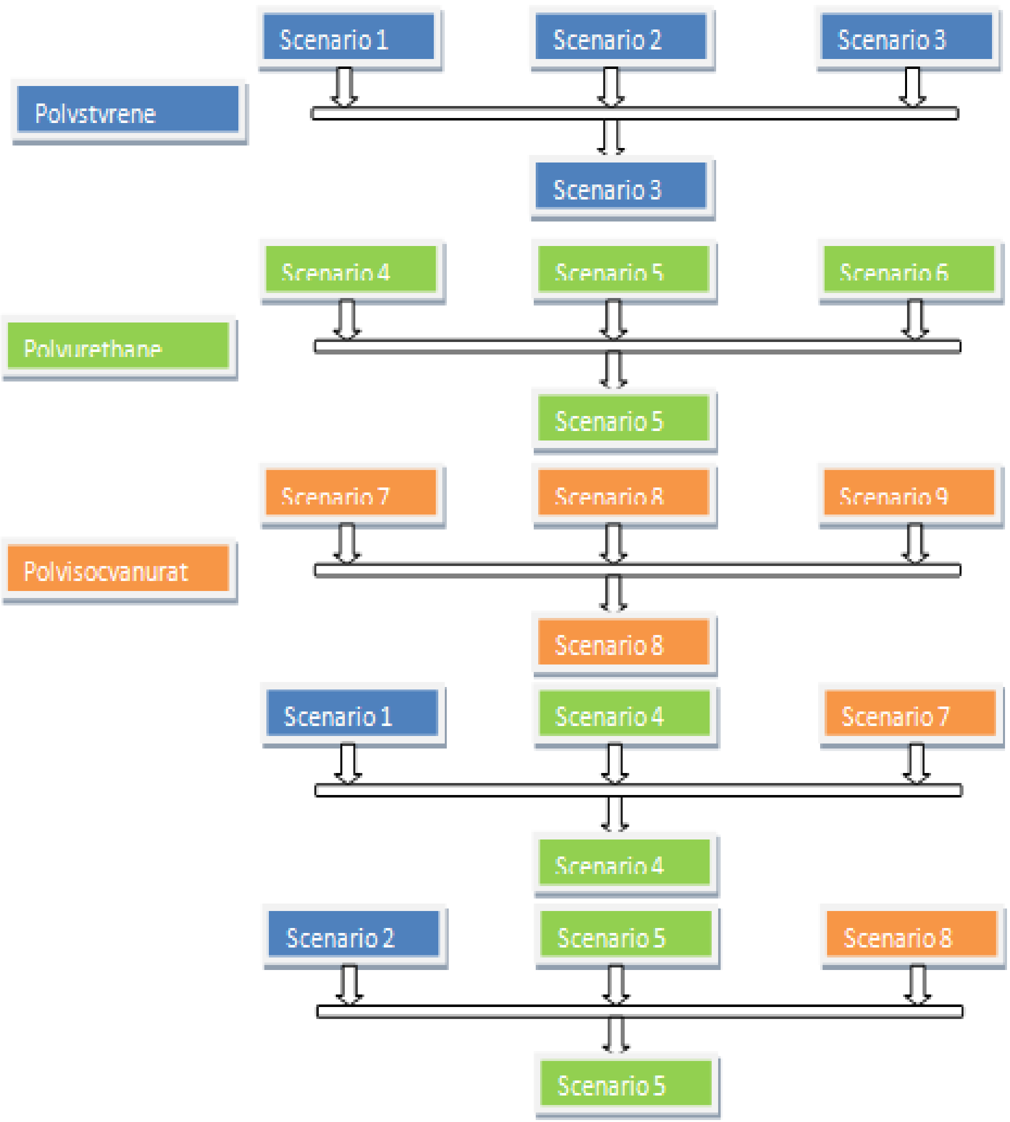

Figure 6.15Flow chart for different glass type scenarios.

6.12.1 Validation of the new model.

In order to validate the proposed model, a comparison between the results of heating space energy consumption given by the simulation for a typical latvian house, an energy efficient house, and a passive house using the U values for exterior envelope, exterior windows, roof and floors, must be performed. Table 4.15 shows differents U values for latvian standard house, energy efficient house, and passive house.

Table 6.15 U value for different type of house

Building parts	Latvian standard	Energy efficient	Passive house
Vertical walls	0.18	0.12	0.09
External windows	1.4	1	0.7
Roofs	0.15	0.15	0.15
Floors	0.09	0.09	0.09

The thickness of the insulation for the conventional house, and passive house according to the work of [**72**] Zemitis and Borodinecs as mentioned in LBN002-01 is given in table 6.16.

Table 6.16 Thickness of insulation in mm

Buiding parts	Conventional house	Passive house
Roof	200	500
Wall	150	500
Floor slab	70	400
Doors U value	1.65	1.17
Windows U Value	1.65	0.7

The conventional external wall configuration is listed in table 4.17, the thermal conductivity W/mK and thermal resistance for interior decoration from reference [**83**], for aerated concrete blocks from reference[**147**], Ecowool from reference [**148**], and decorative plaster from [**149**].

Table 6.17Configuration conventional external wall

Layer	Thickness in mm	Thermal Conductivity, W/mK	Thermal Resistance, R
Interior decoration	15	0.9	0.017
Aerated concrete blocks	250	0.17	1.471
Ecowool	150	0.037	4.054
Decorative plaster	10	0.9	0.011
U value for Wall			0.175

Table 4.18 shows the ground floor configuration, the thickness of the material is kept as for the standard of the construction in Latvia, to prevent the migration of water vapour from the concrete slab to the insulation material, a polyethylene film is added. The insulation thickness is taken as that in reference [**24**], thickness in mm , thermal conductivity of floor lainated plank is taken from reference [**147**], of reinforced concrete mortar smoothing layer and for concrete B7.5 on compacted break stone [**147**]

Table 6.18 Ground floor configuration for conventional house

Layer	Thickness (mm)	Thermal conductivity	Thermal resistance
Floor laminated plank	10	0.12	0.083
Smoothing layer	5		
Reinforced concrete mortar smoothing layer	50	0.17	0.294
Ecowool	70	0.037	1.892
Ployethylene film			
Concrete B 7.5 on compacted break stone	100	0.17	0.588
U value			0.326

The values of external surface resistance are constant and are equal to 0.04, while internal surface resistance, for vertical wall and window 0.13, the value for horizontal surface depends on the heat flux direction if upward direction the value is taken 0.1, if the heat flows downward, the resistance value is taken 0.17[**24**].

The conventional roof configuration is compound of five layers, 2 layers of bituminous roof cover material, with thermal conductivity of 0.13, a layer of plywood of 18mm thickness with R value of 0.138 m^2K/W. a layer of insulation ecowool of 200 mm. with a thermal conductivity of 0.037 m^2K/W, and resistance of 5.405, water vapour insulation film (polyethylene) 0.2 mm, and 60 mm of plaster board on a metal frame. The resistance value of the roof is taken 0.169. The windows and doors U values have been selected according to the required LBN 002-01 building heat envelope (1.4 W/mK for glazing. 1.5 W/mK for frame. and 1.65W/mK for doors).

The thickness of the insulation for the passive house, for external wall, are 15mm for interior decoration with a thermal conductivity of 0.9W/mK, aerated concrete blocks 250mm, and 0.17 W/mK for thermal conductivity, a layer of ecowool of 500mm with 0.037 W/mK of thermal conductivity, and final 10mm of plaster with thermal conductivity of 0.9W/mK.
For the ground floor, the layers thicknesses are kept the same as in conventional house, exept for the insulation of ecowool which has a thickness of 70 mm for a conventional house, but 400 mm for passive house configuration. The passive roof layers composition are 2 layers of bituminous roof cover material, with thermal conductivity of 0.13, a layer of plywood of 18mm thickness with R value of 0.138, a layer of insulation ecowool of 550 mm, with a thermal conductivity of 0.037, and resistance of 5.405, water vapour insulation film (polyethylene) 0.2 mm, and 60 mm of plaster board on a metal frame. The triple glazing window used for the the passice house have a value of 0.7W/mK.

Results of heat space energy consumed for heating season (year 2010) for the latvian conventional house, energy efficient house, and passive house are illustrated in figure 6.16.

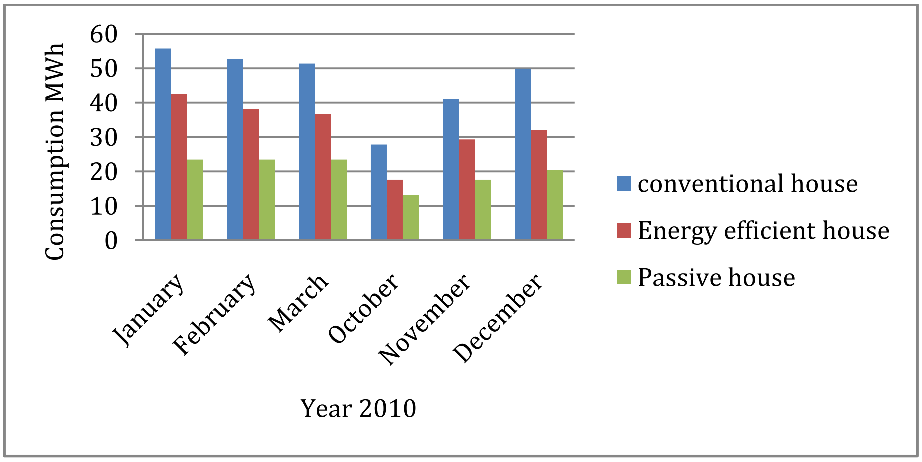

Figure 6.16Comparison between Conventional/energy efficient. and passive house.

6.12.2 New model simulation results.

The comparison of the results of the simulation of the energy consumed for heating season,for the suggested retrofitof the external envelope, for multi-family residential building (Ledurgas 9), when using scenario 5(101.6mm for roof, 76.2mm for wall, and 101.6mm for floor), and when using single low emissivity glass type as chosen for the new model, gives the results shown in figure 6.17.

For the interior building insulation, it was found as cited before, that no significant results were found when compared to external envelope insulation. Figure 6.17 shows the comparison between the recored consumption for the year 2010, and the proposed model consumption.

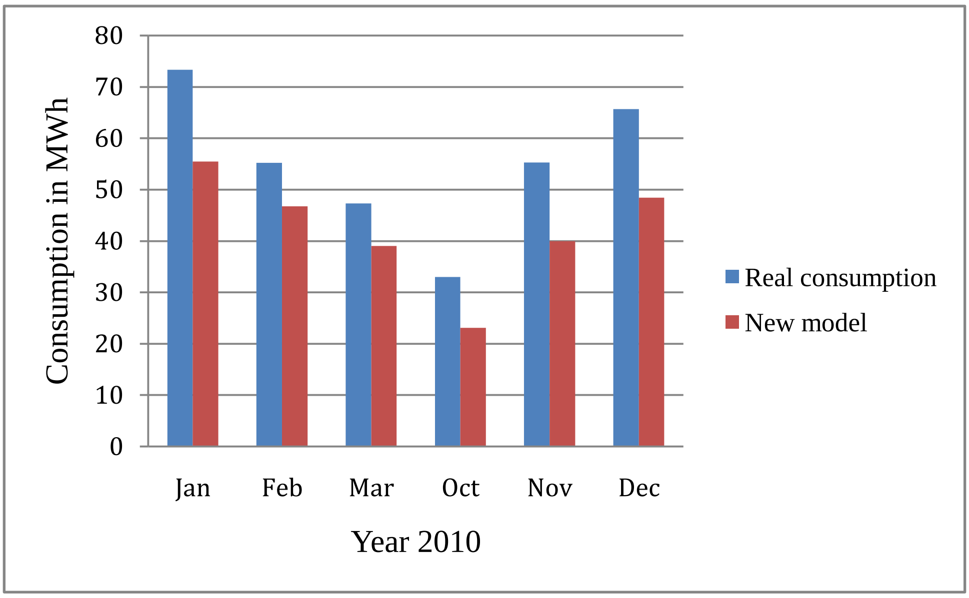

Figure 6.17 New Model versus real consumption.

The mean value of energy consumed during the heating season for the building investigated is 54.98MWh, the proposed model consumption is 42.12MWh with a difference of 12.85MWh gain, which represents a net percentage of gain of 23.56%. The results of energy consumption for the new model are smaller than the consumption of a standard conventional Latvian house as shown in Table4.19

Table 6.19 Comparison of energy consumption of the new model and a conventional house in MWh.

Months	January	February	March	October	November	December
New Model	55	46	39	23	40	48
Conventional house	55	52	51	28	41	50

6.13 Conclusions

6.13.1 Building exterior insulation

In conclusion the use of scenario 2 (101.6mm for roof. 76.2mm for wall, and 101.6mm for floor) as insulation for external envelope is more convenient than scenario 3 (152.4mm in roof, 76.2 mm wall, 127mm floor). The mean different percentage of gain is only 2.52%, while the percentage of added thickness of insulation is is 33.33%, for the roof insulation and 20% for the floor insulation, the wall insulation remaining with the same thickness of 76.2mm.

Scenario 4 (101.6 mm for roof, 76.2mm for wall, and 101.6mm for floor) as insulation for external envelope is more convenient than scenario 6 (152.4mm in roof, 76.2mm wall, 127mm floor). The mean different percentage of gain is only 3.66%, while the percentage of added thickness of insulation remains with the same thickness 33.33%. and 20%.

The use of scenario 8 (101.6mm for roof, 76.2 mm for wall, and 101.6mm for floor) as insulation for external envelope is more convenient than scenario 9 (152.4mm in roof, 76.2mm wall, 127mm floor. The mean different percentage of gain is only 3.99%, while the percentage of added thickness of insulation remains the same as before.

It appears that the use of polyurethane and polyisocyanurate as insulation for external envelope is more efficient than using polystyrene, with the same thickness of 2 inches each. The mean percentage of energy saved in space heating when using polyurethane is 32.57%, and when using the polyisocynurate is 37.18% with a difference of 4.62% between polyurethane and polyisocynurate. If the cost difference is large between polyurethane and polyisocynurate, then the most efficient insulation to be used is polyurethane.

The use of polyurethane and polyisocyanurate as insulation for external envelope seems to be more efficient than using polystyrene, with the same thickness. The mean percentage of energy saved in space heating when using polyurethane is 19.45%, and when using the polyisocynurate is 25.02% with a difference of 5.57% between polyurethane and polyisocynurate. If the cost difference is large between polyurethane and polyisocynurate. then the most efficient insulation to be used is polyurethane.

Use of polyurethane and polyisocyanurate as insulation for external envelope seems to be more efficient than using polystyrene, with the same thickness. The mean percentage of energy saved in space heating when using polyurethane is 19.52%, and when using the polyisocynurate is 25.97% with a difference of 6.45% between polyurethane and polyisocynurate. The most efficient insulation to be used is polyurethane.

6.13.2Comparison between single, double and triple glass energy consumption

The comparison between glass categories, for single clear of 3 mm, double clear, and triple clear, using eQUEST simulation software to estimate the energy consumed for the year 2010, for a multi-rise mid-building in Riga, shows that the comparison between the space heating energy consumption for the three scenarios, when using windows with single glass, double glass, or triple glass, is not as large as in the exterior insulation envelope. The mean monthly space heating energy consumption for scenario 1 (single clear) is equal to 36.06MWh , while it is equal 34.26MWh for scenario 2 (double clear) with a difference of 1.69MWh, which represent 5%. Meanwhile the mean value of energy consumed for scenario 3 (Triple clear) is 33.83MWh with a difference percentage from scenario 2 is equal to just 0.36MWh. This leads to the conclusion that when moving from single to double we have a gain of 5%, but when moving from scenario 2 to scenario 3 we have only 1.26% of benefit. The use of double glass category is best and should be recommended.

6.13.3 Comparison Single low-e , Double low-e, Triple low-e, and quadruple low-e

For scenario 1 (single clear) energy consumption is equal to 36.06MWh, while it is equal to 34.26MWh for scenario 2 (double clear) with a difference of 1.69MWh which represent 5%. Meanwhile the mean value of energy consumed for scenario 3 (Triple clear) is 33.83MWh with a difference percentage from scenario 2 is equal to just 0.37MWh. This leads to the conclusion that when moving from single to double we have a gain of 5%, but when moving from scenario 2 to scenario 3 we have only 1.26% of benefit. The use of double glass category is optimal in energy savings.

Conclusion of the comparison of single low-e, double low-e, triple low-e, and quadruple low-e. The mean monthly space heating energy consumption for single low-e (scenario 4) is equal to 34.31MWh, while the same value for double low-e (scenario 5) is equal to 34.26MWh with a difference of 0.24MWh between consumption in scenario 4 and scenario 5. The difference between double low-e and triple low-e mean value of energy consumed for space heating season is 0.36MWh, which represents a percentage of 1.05%. The difference between triple low-e and quadruple low is 0.69MWh, which represents a percentage of 2.38 % of saved energy when compared to triple low-e consumption. As conclusion, the main value of energy consumption single low-e and double low-e is nearly the same with 0.82% of difference while it remains also small but with a percentage of 1.23 for consumption between double low-e and triple low-e, and rise to 2.38 % for quadruple low-e. The use of double low-e is optimal in energy savings.

6.13.4 Comparison Single/Single low-e , double/double low-e, triple/triple low-e, and quadruple/quadruple low-e

The difference between heat space consumption when using single low-e instead of single is the biggest difference value. The difference between single low-e and double is insignificant the mean value of consumption of single low-e is 34.26MWh for the heating season, while when using double is 34.26 MWh, the mean value of consumption of double low-e is 34.26MWh, which equal to the single low-e value, for triple glass category, the mean consumption is 33.83MWh, the triple low-e consumption is 33.71MWh, with a difference from just triple with a difference of 0.117MWh bigger than the consumption of triple low-e, which is equal to 33.71MWh. The difference between double and double low-e is equal to 0.184MWh, and the difference between single and single low-e is 1.99MWh.The use of single low-e is optimal in energy savings**.**

As a general conclusion the comparison between single , double and triple clear glass category shows that the optimal is double clear, between single low-e, double low-e, triple low-e and quadruple low-e, the optimal values are single low-e and double low-e and quadruple low-e. The comparison between single/single low-e, double/double low-e, and triple/triple low-e, shows that single low-e and double low-e are optimal, The optimal over all comparison is the double glazing low-e.

For the proposed model, the mean value of energy consumed during the heating season for the building investigated is 54.98MWh, the proposed model consumption is 42.12MWh with a difference of 12.86MWh gain, which represents a net percentage of gain of 23.56%.

More investigation is needed to compare the effect of differents insulation materials used in the building envelope, and the impact of the cost on the choice of the material type should be invesigated. A comparison of the energy savings and the cost difference between insulation material is needed before chosing which insulation is the most adequate.

GENERAL CONCLUSIONS

7.1 Energy consumption

As a general conclusion for the world consumption, the trend and shape of the world energy consumption is fundamental for economics and sustainability. The increase in energy demand and consumption, the climate change, and the limited fossil fuel resources will urge policy makers and deciders to adjust their energy strategies and address future energy needs. Renewable energies should be introduced with more sharing in total final energy consumption, and substitute the most polluting traditional energy sources, which are not only harmful to the environment but also are finite in the long term.

For European union, in the last decade, the residential sector energy consumption has started to decrease. The decreasing trend continued until the year 2010 when consumption grew again, between 2004 and 2009 total final residential energy consumption in the EU-27 fell down by a percentage of 2%, reaching the lowest consumption level of the last 20 years in 2007. Meanwhile, this very important decrease (-4% compared to 2006) in 2007 could be explained by the warm temperatures during this year that resulted in a lower number of heating degree days compared to the average heating days. Between the years 2005 to 2010, total final energy consumption in EU-27 decreases by -3.29%. The level of energy consumption of 2009 is nearly the same, as 10 years earlier. The total final energy consumption in EU-27 increases by 3.25% since 1990. In year 2005, consumption increased and reached 138.397×10^5 TWh, then it started decreasing by -5.2% until 2008 but between 2009 and 2010 consumption increased by 3.56%.

Between 1991 and 2009 electricity consumption in the non-residential sector has increased by 66% in the EU-27.

In Algeria**,** The percentage of the average growth in the residential and tertiary sector is merely the same as in petrol industry, the transport has an average less than in the petrol industry. Whereas, both industry - building construction, and agriculture –water resources illustrate a percentage value more than that of the petrol industry. The total energy annual growth consumption counts for 0.32TWh, therefore producing annual amount of 76.44 $MTCO_2$. Total energy consumption distribution by fuel type shows that the oil is the most combustible consumed. This is due to the growing industry demand and transport. The consumption of natural gas for industrial purposes, such as electricity production by thermal stations using natural gas comes in second place because of the increasing demand in residential and tertiary, as well, as in energy-industry, and non-energy industry. The increasing demand for electricity represents 12%.

7.2 eQUEST and EnergyPlus

The results of the comparison of two major whole building simulation programs(eQUEST and EnergyPlus) shows quite big differences, when we are dealing with the annual energy consumption, the eQUEST results are much closer than the EnergyPlus results. The difference between the measured annual electrical energy consumption, and the simulated one using eQUEST program, are +/- 0.95% for January and October, the highest difference percentage registered is 12.38% for the month of March. The others oscillate between +/- 6%. and +/- 1%. Whereas, the same results, but when using EnergyPlus program, show a difference of 18% and 8%. Table 5 shows the detailed difference percentage between eQUEST and EnergyPlus, and it shows clearly that the results obtained when using eQUEST are closer than when using EnergyPlus.

The difference percentage between the simulated results using EnergyPlus and the measured values for annual gas consumption is larger than the percentage of difference when using eQUEST program.

7.3 Riga multifamily houses mid-rise building consumption

As it has been showed before that the eQUEST gives results closer to the recorded results. The average heat space energy consumption, in kWh/m^2 for cold season (January. February. March. October. November December), and for building 9, was found to be 146.61 in year 2010, 130.27 in 2011, 139.17 in 2012, and 132.91 in 2013, with an average of 137.24 for the period of 4 years between 2010 and 2013. And the simulated for the same building was found to be was found to be 151.78 in year 2010, 151.77 in 2011, 151.67 in 2012, and 151.92 in 2013, with an average of 151.79 for the period of 4 years between 2010 and 2013.

The average heat space energy consumption for cold season in kWh/m^2 (January. February. March. October. November December), for building 7, was found to be 175.49 in year 2010, 159.45 in 2011, 164.19 in 2012, and 164.19 in 2013, with an average of 165.83 for the period of 4 years between 2010 and 2013. And the simulated for the same building was found to be was found to be 163.41 in year 2010, 163.36 in 2011, 163.33 in 2012, and 163.57 in 2013, with an average of 163.42 for the period of 4 years between 2010 and 2013.

It was also noticed that the mean measured values for building 9 were found to be smaller than the average simulated values during the period 2010-2013, with an average closeness percentage of 90.42%, meanwhile, for building 7, and for the same period, the mean simulated values were found to be smaller than the measured ones with an average closeness percentage of 98.54%.

The average energy consumption for the heating season in kWh/m^2, for the four years analysed, have a value of 137.24kWh/m^2, and a simulated value of 151.79kWh/m^2, for

Lēdurgas 9, 165.83kWh/m^2, and 163.42kWh/m^2 for Lēdurgas 7, 137.28kWh/m^2, and 150.31kWh/m^2 for Mores7, 130.59 kWh/m^2, and 150.49 kWh/m^2 for Mores5, 156.29 kWh/m^2 and 164.35 kWh/m^2 for Mores3, 143.92 kWh/m^2 and 161.14 kWh/m^2 for Ostas4, and finally 138.92 kWh/m^2 and 154 kWh/m^2 for Ostas6. The overall average for the seven buildings investigated, and for the four years, have a value of 144.3 kWh/m^2 as a measured value, and 156.50 kWh/m^2.

7.4 External envelope insulation different scenarios

As a conclusion the use of polyurethane and polyisocyanurate as insulation for external envelope seems to be more efficient than using polystyrene, with the same thickness of 50.8mm each. The mean percentage of energy saved in space heating when using polyurethane is 32.57%, and when using the polyisocynurate is 37.18% with a difference of 4.62% between polyurethane and polyisocynurate. The cost of polyurethane spray foam with a thickness of 25.4 mm and a thermal resistace of 1.14m^2K/W, is 18.33 USD per m^2, and 7.22 USD per m2 for for the same thermal resistance polyisocynurate, then the most efficient insulation to be used is the polyisocynurate.

The use of polyurethane and polyisocyanurate as insulation for external envelope seems to be more efficient than using polystyrene with the same thickness. The mean percentage of energy saved in space heating when using polyurethane is 19.45%, and when using the polyisocynurate is 25.02% with a difference of 5.57% between polyurethane and polyisocynurate.

The conclusion of the use of polyurethane and polyisocyanurate as insulation for external envelope seems to be more efficient than using polystyrene. with the same thickness. The mean percentage of energy saved in space heating when using polyurethane is 19.52%. and when using the polyisocynurate is 25.97% with a difference of 6.45% between polyurethane and polyisocynurate. The most efficient insulation to be used is the polyisocynurate.

7.4.1. Building exterior windows

As a general conclusion the comparison between single, double and triple clear glass category shows that the optimal is double clear between single low-e, double low-e, triple low-e and quadruple low-e, the optimal values are single low-e and double low-e and quadruple low-e. The comparison between single/single low-e, double/double low-e, and triple/triple low-e, shows that single low-e, and double low-e are optimal. The optimal over all comparison is the double glazing low-e.

For the proposed model, the mean value of energy consumed during the heating season for the building investigated is 54.98 MWh, the proposed model consumption is 42.12 MWh with a difference of 12.86MWh gain. which represents a net percentage of gain of 23.56%.

More investigation is needed to compare the effect of differents insulation materials used in the building envelope. and the impact of the cost on the choice of the material type should be invesigated. A comparison of the energy savings and the cost difference between insulation material is neede before chosing which insulation is the most adequate.

8. Conclusions

1) The results of comparison of two major whole building simulation programs, shows that, when we are dealing with the annual energy consumption, the eQUEST results are much closer than the EnergyPlus results. It gives better results for largest number of cases. The difference between the measured annual electrical energy consumption and the simulated one using eQUEST program is +/- 0.95% for January and October, the highest difference percentage registered is 12.38% for the month of March. The others oscillate between +/- 6%, and, +/- 1%. Whereas, the same results, but when using EnergyPlus program, show a difference of 18% and 8%.
2) For the general modelling features, the simulation of the BLAST, DOE2.1E, TRACE, have a sequential loads, system, plant calculation without feedback, for simultaneous loads, system and plant solution almost all the programs perform the simulation except DOE2.1E, ECOTECT, and TRACE. For iterative non-linear systems solution, only the programs BLAST, DeST, DOE2.1E, Ener-Win, Energy express, eQUEST, and SUNREL do not perform the iterative non-linear systems solution. Softwares, BLAST, DeST, DOE2.1E, ECOTECT, Ener-Win, HAP, Tas, and TRACE, do not offer coupled loads, systems, plant calculations. The DOE2.1E, the eQUEST, they do not simulate space temperature based on loads-systems feedback. All the programs simulate the floating room temperatures.
3) For the time step approach, the user selected for zone/environment interaction, nearly 50% of the software did not give this opportunity. For variable time intervals for zone air/HVAC system interaction, only, BLAST, BSim, Energy Express, Energy plus, eQUEST , and ESP-r, offer air/HVAC system interaction. User selected for both building and systems, only ESP-r, IDA ICE, IES VE, PowerDomus, and TRNSYS, which offer this opportunity. The EnergyPlus, ESP-r, IDE ICE, offer dynamically varying based on solution transients; all the others do not offer this possibility. While, all the softwares

offer the full geometric description, walls, roofs, floors, windows, skylights, doors, and external shadings.

4) In the last decade the residential sector energy consumption in European Union has started to decrease. The decreasing trend continued until the year 2010 when consumption grew again between 2004 and 2009, total final residential energy consumption in the EU-27 fell down by a percentage of 2%, reaching the lowest consumption level of the last 20 years in 2007. This very important decrease (-4% compared to 2006) in 2007 could be explained by the warm temperatures during this year that resulted in a lower number of heating degree days compared to the average heating days. Between the years 2005 to 2010, total final energy consumption in EU-27 decreases by -3.29%.
5) The energy audit program energoaudits.eu and adapted by standard LVS EN ISO 13790/2009 is a program that enables the calculation of the, energy performance of building, and the calculation of the feasibility of energy actions like insulations, replacement of windows, boilers etc. Although this program is very easy for everyone to use, without the need to be architect or engineer, but this program do not take in consideration very important variables, such as, climatic zones, weather conditions, architectural shape of building, orientation, and so on. Hence, it has not been used in this study.
6) The results of simulation by the eQUEST, as it has been showed before that the eQUEST gives results much close to the recorded results. The analysis of energy consumption in multi-family mid-rise buildings in Riga shows that the average heat space energy consumption for cold season (January. February. March. October. November December) in kWh/m^2, for building 9, have an average of 40.25MWh for the period of 4 years between 2010 and 2013. And the value found by simulation for the same building have an average of 44.51MWh for the period of 4 years between 2010 and 2013.
7) The conclusion of the use of polyurethane and polyisocyanurate as insulation for external envelope seems to be more efficient than using polystyrene. with the same thickness. The mean percentage of energy saved in space heating when using polyurethane is 19.52%. and when using the polyisocynurate is 25.97% with a difference of 6.45% between polyurethane and polyisocynurate.
8) For the building external windows, and as a general conclusion the comparison between single, double and triple clear glass category shows that the optimal is double clear, between single low-e, double low-e, triple low-e and quadruple low-e. The optimal values are single low-e and double low-e and quadruple low-e. The comparison between

single/single low-e, double/double low-e, and triple/triple low-e, shows that single low-e, and double low-e. The optimal over all comparison is the double-glazing low-e.

9) According to the DOE, typical heat loss through roof is 25% of total heat loss, 35% through wall, and 10% through floor, with a total of 70%. The most energy efficiency measure would be the improvement of insulation applied on the envelope. The heat loss through the windows is about 15% in typical residential building, but in office and commercial buildings the glass facades are more and more increasing, and the reduction of heat loss through glasses is more important.

10) For the proposed novel model. the mean value of energy consumed during the heating season for the building investigated is 54.98MWh, the novel model consumption is 42.12MWh with a difference of 12.89MWh gain. which represents a net percentage of gain of 23.56%.

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